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February 16, 2005

Manager Alan Mitchell
Minnesota Environmental Quality Board
Room 300
658 Cedar Street
St. Paul, Minnesota 55155

RE: Xcel Energy Route Permit Application

Dear Manager Mitchell:

I serve as General Counsel for Interstate Telecommunications Cooperative, Inc. (ITC) I appeared at the afternoon public hearing on the 3rd day of February, 2005, at the Midwest Center for Wind Energy near Hendricks, Minnesota, to object to any permit being granted unto Xcel Energy by the Minnesota Board of Environmental Quality until it is determined that the proposed 115kv high voltage transmission line will not cause any interference with the rural telecommunications lines maintained, operated and owned by ITC. First, I am enclosing a copy of the ITC Telecommunication Inductive Interference Report prepared by Wilkins Consulting regarding existing inductive interference induced by the Buffalo Ridge wind turbine generator collector system onto the ITC telecommunication system. This report includes maps of specific areas tested in 2003 for interference which commenced in July, 1999, and continues as of the current date.

Second, Exhibit #22 was accepted at the public hearing and shows the location of the transmission lines maintained, operated and owned by ITC within the various routes proposed by Xcel Energy for its new high voltage 115kv transmission line. Third, the letter by ITC General Manager Jerry Heiberger dated the 14th day of October, 2004, to Chairman Larry B. Hartman was accepted at the public hearing as Exhibit #23. A critical point set forth in Manager Heiberger's recent letter is in the second paragraph on page 2 stating "engineers can predict the level of interference that may be produced <u>before</u> the transmission line is installed." (emphasis added)

Fourth, I am submitting a copy of a letter dated the 14th day of September, 2000, by the former ITC General Manager, Dean Anderson, to Mr. Kalyan K. Mustaphi, Executive Engineer for Northern States Power Company, regarding extensive tests that confirmed the noise induction adversely affecting the transmission lines of ITC "is directly related to the power generated by the wind farm." Neither Mr. Mustaphi nor Northern States Power Company ever responded.

EXHIBIT 26
MEQB Docket
04-84-TR-Xcel

Fifth, I am submitting a copy of a letter dated the 22nd day of August, 2001, by the former ITC General Manager, Dean Anderson, to Mr. Kalyan K. Mustaphi, Executive Engineer for Xcel Energy, regarding the induced noise not having been entirely eliminated, particularly near the substation of Xcel Energy and its associated capacitor banks located southeast of Lake Benton, Minnesota. Mr. Mustaphi never responded. Rather, there was a letter dated the 15th day of October, 2001, by Assistant General Counsel for Xcel Energy, Mr. James L. Altman, regarding Xcel Energy not being responsible for any noise problem emanating from the wind turbines. However, Mr. Altman's letter fails to address the responsibilities of Xcel Energy regarding the noise problems emanating from elsewhere.

Sixth, I am submitting a copy of a letter dated the 3rd day of May, 2002, by Keith A. Bartels, P.E., a consultant hired by ITC regarding the induced noise problems experienced by ITC in the Lake Benton area. I ask that particular emphasis be placed on subsection (7) through the end of the letter by Mr. Bartels regarding the lack of any courtesy, cooperation or effort by Xcel Energy addressing the induced noise interference created by the wind turbine system.

Seventh, I am enclosing a copy of a page from an earlier Power Point presentation by ITC General Manager Jerry Heiberger which reflects that 100% of 850 Lake Benton access lines were affected in the summer of 1999 as a result of the interference problem created by the wind turbine system.

Eighth, I am enclosing a copy of a letter dated the 25th day of January, 2005, by Mr. Gary Karn, Project Manager for Xcel Energy, which states that "Xcel Energy is committed to finding a solution to the telecommunications interference problem your company and customers have been experiencing in and around the area near Lake Benton, Minnesota. …we would be evaluating the impacts of this 115kv line in conjunction with the IEEE Standard 776 as well as IEEE 519. Our goal is to work with your company to identify and resolve existing issues as well as potential issues involving the proposed 115kv line to White Sub. You can look forward to our continued cooperation in finding the answers needed for both of our facilities to productively co-exist." It is ironic that ITC receives this letter from the project manager for Xcel Energy just eight days prior to the public hearing on the 3rd day of February, 2005. Indeed, Xcel Energy states that ITC may look forward to "our continued cooperation" when in fact there has been very nominal cooperation at anytime by Xcel Energy for more than five years. In other words, we submit that this letter is merely for purposes of appeasing the Minnesota Environmental Quality Board just for the moment. Once the Minnesota Environmental Quality Board grants Xcel Energy the permit desired, then there will be nothing more done or said in anyway whatsoever by Xcel Energy regarding past or present noise problems experienced by ITC customers.

Finally, I ask that the Inductive Interference Report by Wilkins Consulting, Inc., and the two letters by former ITC General Manager Dean Anderson, plus the letter by Mr. Keith Bartels, and the page from ITC General Manager Jerry Heiberger's Power Point presentation, together with a copy of Project Manager Gary Karn's letter, be marked as exhibits and admitted into the record of this permit application by Xcel Energy. Furthermore, ITC submits that the following language be included in any permit issued hereafter by the Minnesota Environmental Quality Board to Xcel Energy regarding this proposed route:

> The permit applicant, Xcel Energy, shall first meet with the representatives of Interstate Telecommunications Cooperative, Inc., prior to any construction or installation being commenced, and discuss any concerns with the location or engineering design of the 115kv transmission line, including the avoidance of interference that exceeds existing standards which may be caused by the project. Additionally, the level of interference that may be produced by the transmission line shall be predicted before the construction or installation thereof commences. Furthermore, the permit applicant, Xcel Energy, must fulfill, comply with and satisfy all IEEE industry standards on this project, including but not limited to IEEE 776 and IEEE 519. In the event it is subsequently discovered that any IEEE industry standard has not been fulfilled or satisfied, then a hearing will be scheduled forthwith before the Minnesota Environmental Quality Board upon written notice being received by said board regarding the specific IEEE standard being breached or violated.

Thank you for allowing ITC to submit this additional information. Please be certain to keep ITC advised regarding this application as it progresses.

Sincerely,

GUNDERSON, EVENSON, BOYD,
KNIGHT & STOLTENBURG, LLP

Todd D. Boyd

Todd D. Boyd

TDB/kh
Encl.

cc: General Manager Jerald J. Heiberger, ITC

Wilkins Consulting

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ITC Telecommunication Inductive Interference

Report

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Table of Contents

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Background:

The purpose of this report is to identify the magnitude and cause of inductive interference that is induced by the Buffalo Ridge wind turbine generator collector system onto specific segments of the Interstate Telecommunication Cooperative (ITC) telecommunication system. ITC is located at 312 4th Street West, Clear Lake South Dakota 57226. ITC owns, operates and maintains the Lake Benton exchange where reports of "telecommunication interference" are occurring. Wilkins Consulting located at 21341 golden hills blvd #D, Tehachapi California was contracted to conduct testing within the Lake Benton exchange and generate a report which identifies the following:

1) The cause of the telecommunication interference
2) Possible solutions to the cause.

To characterize the interference, Wilkins Consulting along with ITC directed Energy Maintenance Service (EMS) located at 129 Main Ave, Gary South Dakota, 57237 to perform testing along (1) certain points of right-of-way, (2) collector system interconnection points and at (3) residence customer locations in which service may be adversely effected by the collector system. During the months of May, 2003 through July 2003 Jim Mikel, John Hovland and Wade Wiechmann all of EMS performed testing for the purpose(s) listed in 1 and 2 above. Data was sent to Wilkins Consulting and analyzed by Thomas Wilkins of Wilkins Consulting. Wilkins Consulting used IEEE 776 and IEEE 367 to evaluate the test data and compile this report. ITC requested that the report be sent to Keith Bartels of Martin and Associates for further evaluation.

Procedural Note:

The test plan has changed from the original due to new information discovered that directed the test plan be changed and also testing time limits at the point of interconnection. Specifically, test procedures given by the Institute of Electronic and Electrical Engineers (IEEE)

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standard 776 and standard 367 were adapted and modified into the test. Furthermore, due to the variable nature of the wind and operational as well as technical issues at the point of interconnection only data on one phase was obtained; however, it was determined that single phase oscillography would be enough data to assist us in determining a cause effect relationship as well as a proposed solution to this interference problem.

Note to the reader. All graphs are accurate to the 50th harmonic. For greater than 50 the values are estimated.

Introduction:

The basic building block for telephony transmission is the voice channel. "Voice Channel" is defined as the transmission path for voice communication over, wire, radio, coaxial cable, or over a fiber optic system. In the case of this study only voice communications over copper wire will be studied. The primary content of a voice signal occupies a much narrow band of frequencies than what the human voice contains, consequently the band of frequencies under primary consideration is300 to 3400 hz. However, higher frequency will be analyzed due to the importance of digital communications and the Internet.
There are five basic impairments to the voice channel along with higher frequencies. They are:

- Attenuation Distortion
- Phase Distortion
- Noise
- Echo
- Singing.

Noise in its broadest sense consistent of any undesired signal in a communication circuit. The subject of noise reduction is the primary consideration of this report. Noise can be broken up into four major categories. They are:

- Thermal Noise
- Intermodulation noise
- Cross talk
- Impulse Noise.

Thermal noise occurs across all transmission media and all communication equipment. It arises from random motion of electrons within the various transmission mediums. Thermal noise sets up the lower limit of sensitivity of a receiving system. Thermal noise is a general expression referring to noise based on thermal agitations.

Intermodulation(IM) noise is the result of the presence of intermodualtion products. If two signals with frequencies f1 and f2 are passed through a non-linear device or medium, the result will contain IM products that are spurious frequency energy components. These components may

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present either inside and or outside the band of interest of the particular device. IM products may be produced from harmonics or as one of the signals and the harmonic or the other, or between both signals themselves. The products result when two or more signals best fit together or "mix". Look at the mixing possibilities when passing F1 and F2 through a nonlinear device. The coefficients indicate the first, second, or third harmonics.

- Second order products F1+_F2
- Third Order products 2F1+- F2, 2F2+-F1
- Fourth order products 2F1+-2F2, 3F1+-F2.....

Devices passing multiple signals simultaneously develop intermediation noise that resembles white noise. IM noise may result from a number of causes: (1) Improper level setting, If the level of input to a device is too high, the device is driven into nonlinear operating region, (2) Improper alignment causing a device malfunction non-linearity, (3) Non-linear envelope delay.

Level or "signal magnitude" in the context of this report is will be referred to in the absolute sense. It will be given in units of DBm. DBm is defined as "DBm is decibels referenced to one milliwatt and milliampere". In telecommunication networks if levels are set to high, amplifiers become overloaded, resulting in increased intermodulation noise or increased crosstalk, if levels are set to low, customer satisfaction may suffer.

Crosstalk refers to unwanted coupling between signal paths. There are primarily three causes of crosstalk.(1) electrical coupling between transmission media, (2) poor filter design, (3) non linear performance in analog systems.

Impulse noise is non-continuous, consisting of irregular spikes and pulses for a short duration and are relatively high in amplitude.

From IEEE 776 the primary mode of noise in this case is crosstalk, which exists between the transmission system and telecommunication system. The power signal from the power system is coupling onto the telecommunication system along the same right of way. One of the goals of this paper is to find out how much coupling is occurring and does he noise level exceed existing standards. However this is not the only point that is studied.

IEEE776

As stated in IEEE standard 776 it is "the recommended practice for Inductive coordination of electric supply and communication lines This recommended practice addresses the inductive environment that exists in the vicinity of electric power and wire-line telecommunications systems and the interfering effect that may be produced thereby; guidance is offered for the control or modification of the environment and the susceptibility of the affected systems in order to maintain an acceptable level of interference. To aid the user of this recommended practice in calculating induction between power and telecommunication lines, the concept of an interface is developed. This recommended practice permits either party, without need to involve the other, to verify the induction at the interface by use of a probe wire. This recommended practice does not apply to railway signal circuits.

Inductive interference is defined as an effect, arising from the characteristics and inductive relations of electric supply and telecommunication systems. It is of such character and magnitude that it would prevent the telecommunication circuits from rendering service satisfactorily and economically if methods of inductive coordination were not applied. Inductive interference is produced by the simultaneous coexistence of three factors:

a) An inductive influence

b) A coupling mechanism between two electrical systems or circuits, one of which produces the Influence

c) A susceptibility of the second system or circuit to interference

While inductive interference may occur at any time the above conditions are satisfied, the majority of cases and the principal concern of this recommended practice involve interference in telecommunication systems as a result of their proximity to electric power systems. Therefore, subsequent discussion is limited to that general case, although the principles and practices may apply to other cases as well."

Location and Site Background

There are three wind sites, which surround the Lake Benton Exchange. Lakota, Shakotan and Lake Benton Phase1. The Lake Benton exchange is surrounded by the Lake Benton 1 wind plant facility made up of 141 Zond™ 750 wind turbine generators (WTG). The WTGs are of a unique design. Instead of using a squirrel cage generator Zond deployed a wound rotor generator with extended slip operation to enhance its production. In order to achieve extended slip operation the generator is coupled to a dual matrix converter/inverter coupled by a DC link, four quadrant, which is pulse width modulated. The converter/inverter is a switch mode power processor, which processes the power input from the wind. The converter inverter switches at frequencies of 1 and 8 kHz. These frequencies are important for this study.

Squirrel cage and Wound Rotor Generator

Figure 1 is the single line circuit of the Zond™ 750 Wind Turbine Generator using a wound rotor induction generator. A Converter/ Inverter capable of regulating power to and from the rotor is

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connected across the rotor and stator and acts as the power processor for the generator.

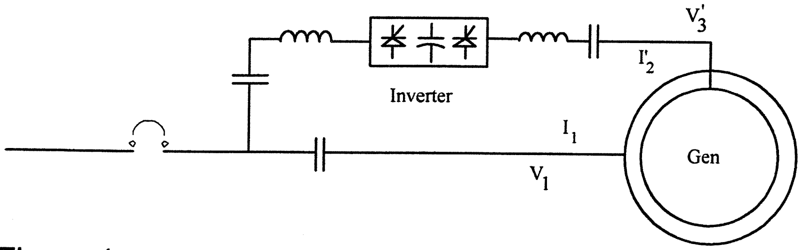
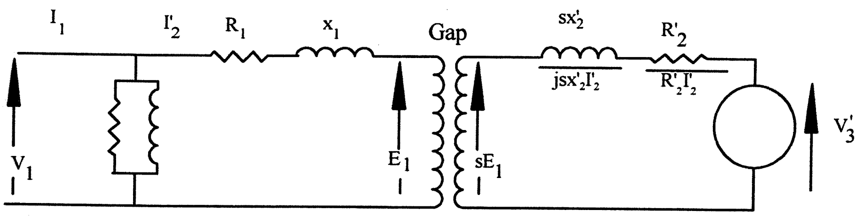


Figure 1

The single line circuit is given in figure 2. V3 represents the voltage injected by the inverter converter. For a squirrel cage model short the terminal across V3'.



Equivalent wound rotor induction generator model with secondary injected voltage V3'

Figure 2

Testing Locations:

From IEEE standard 776 and 367, a testing method was developed to determine the coupling between the power and telecommunication system. This method is given in the "test reports" for each section. Given below are the areas that were tested:

Sections 5, 12,15,31,34,and 35 are where the wire probe tests were conducted. Please refer to the map to find the area where each test took place. The above sections were chosen due to the amount of paralleling that occurs between the two systems.

Also direct measurements were made on customer's lines at the place of residence, they are:

1) Arnold Garbers Location RST 5-1-1-1 ONU 4-1 Rt A/9 CP. 2
2) Steven Lynn Location RST 5-1-10-1 ONU 4-55 Rt B1/8 CP 27
7) Ed Brockhouse Location RST 1-1-7-1 ONU 1-37 Rt D/14 Cp-2

These customers were chosen due to poor signal quality and customer complaints. Given on the following pages are the maps, which indicate the location of the customers and sections tested. Please refer to the numbers next to the names above to find them on the map. Test data is given on the CD with report. The data is in raw format and can be viewed using

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"Wavestar reader™" it can be downloaded via the Tektronix website at tec.com.

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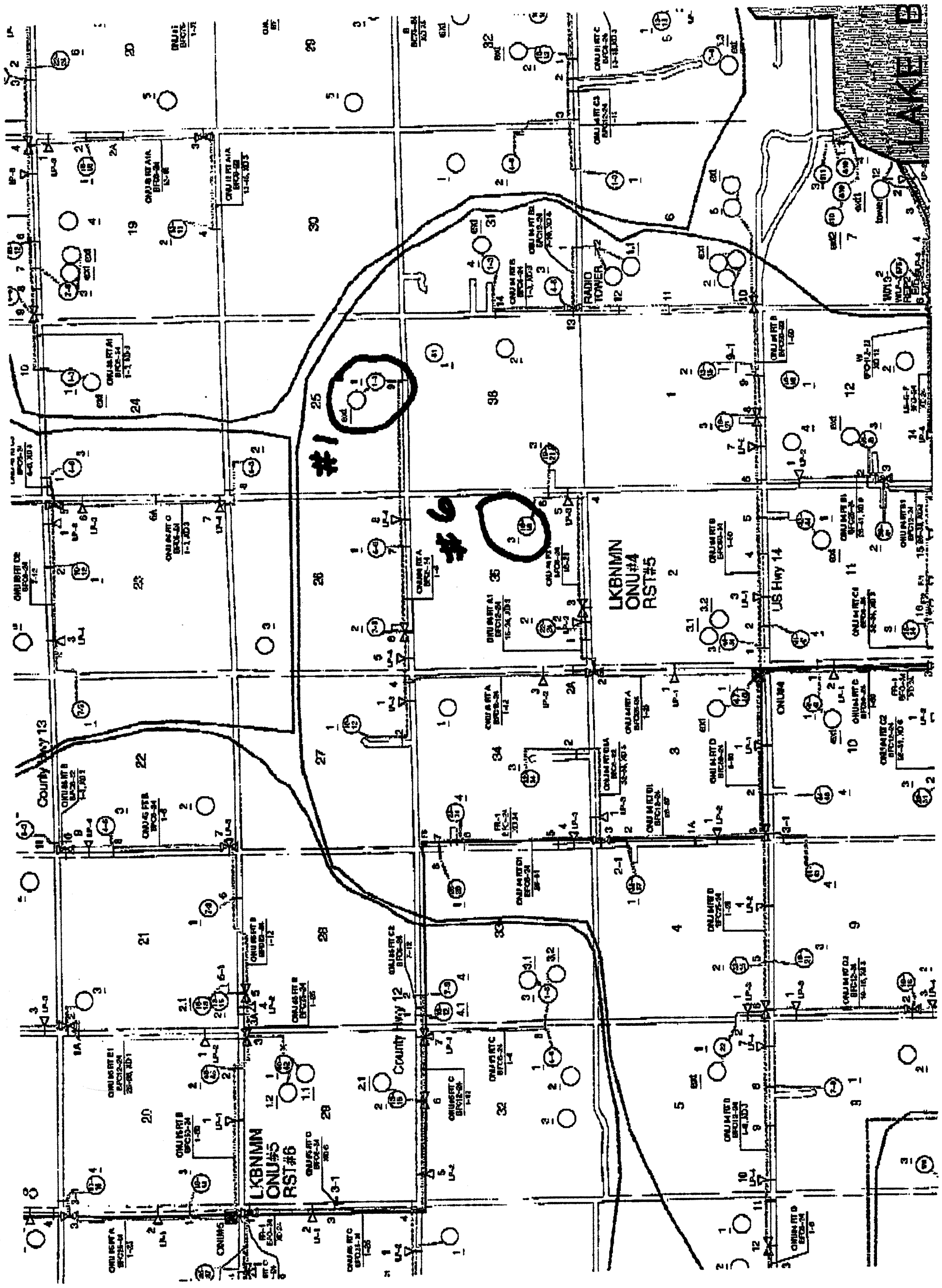

Map A

Figure 3
Figure 1

Wilkins Consulting

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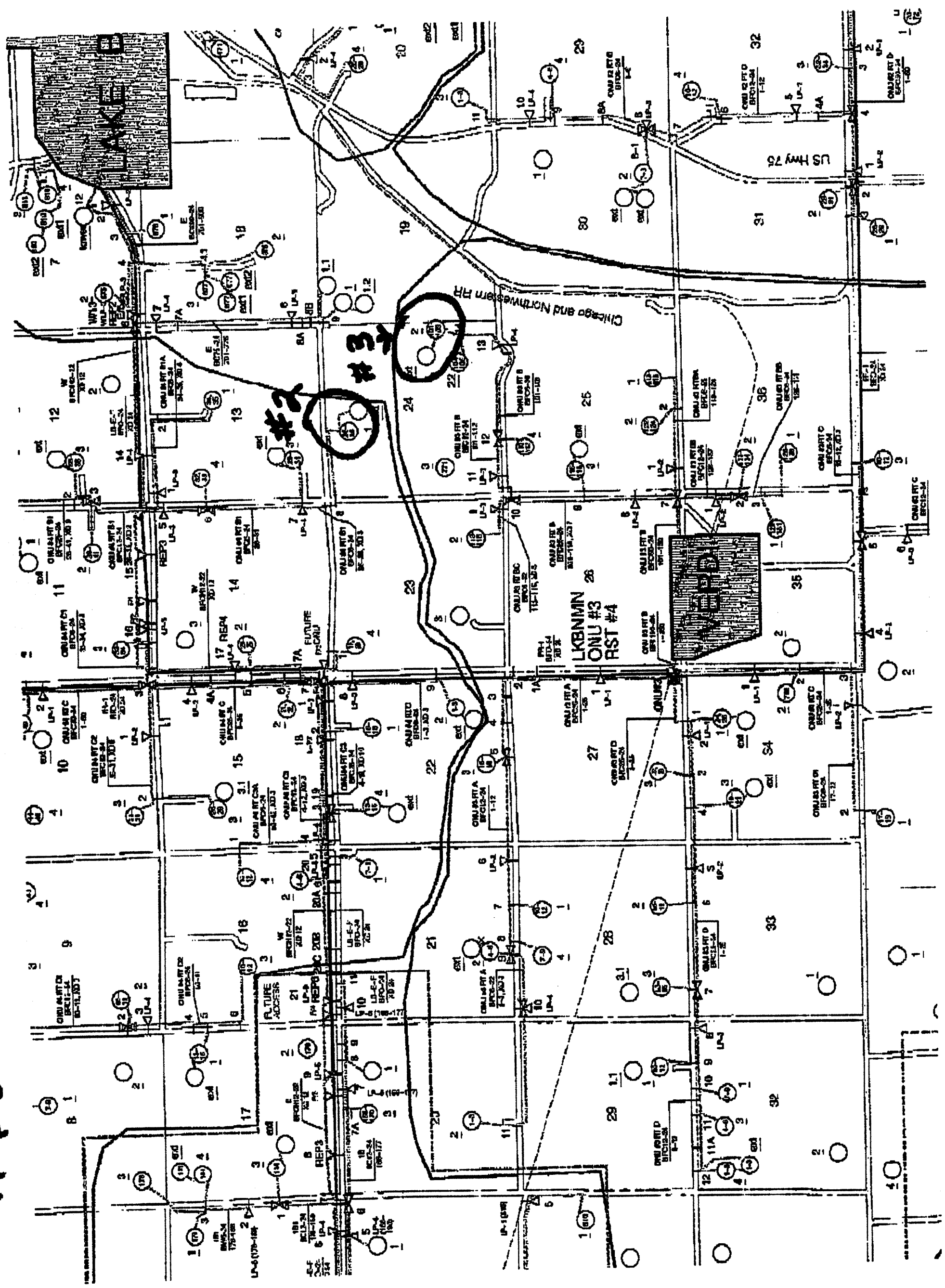

Map B

Figure 4

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Monday, May 19, 2003 6:43 AM——Ren Preheim 605-874-2606 p.05

Map C

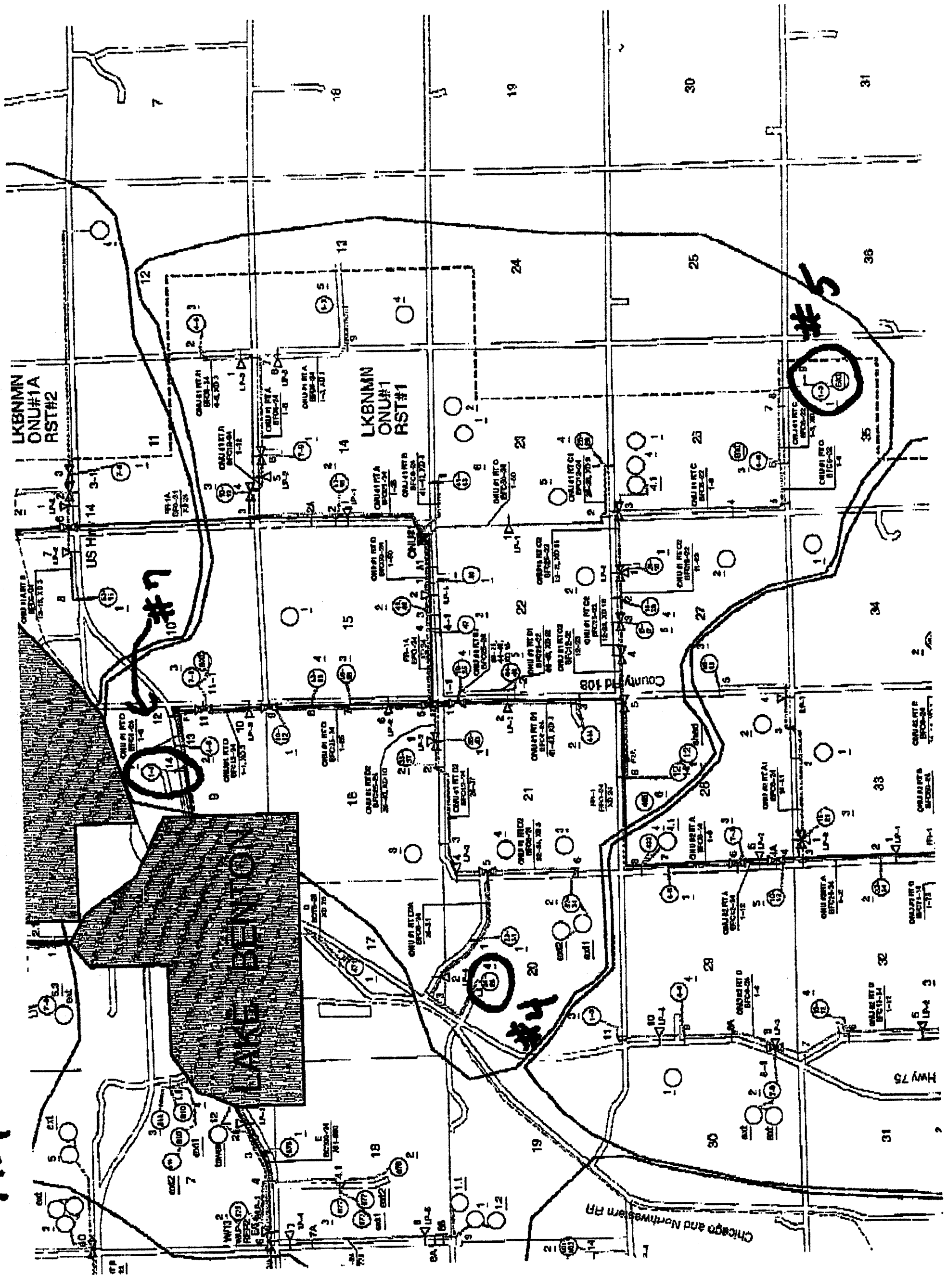

Figure 5

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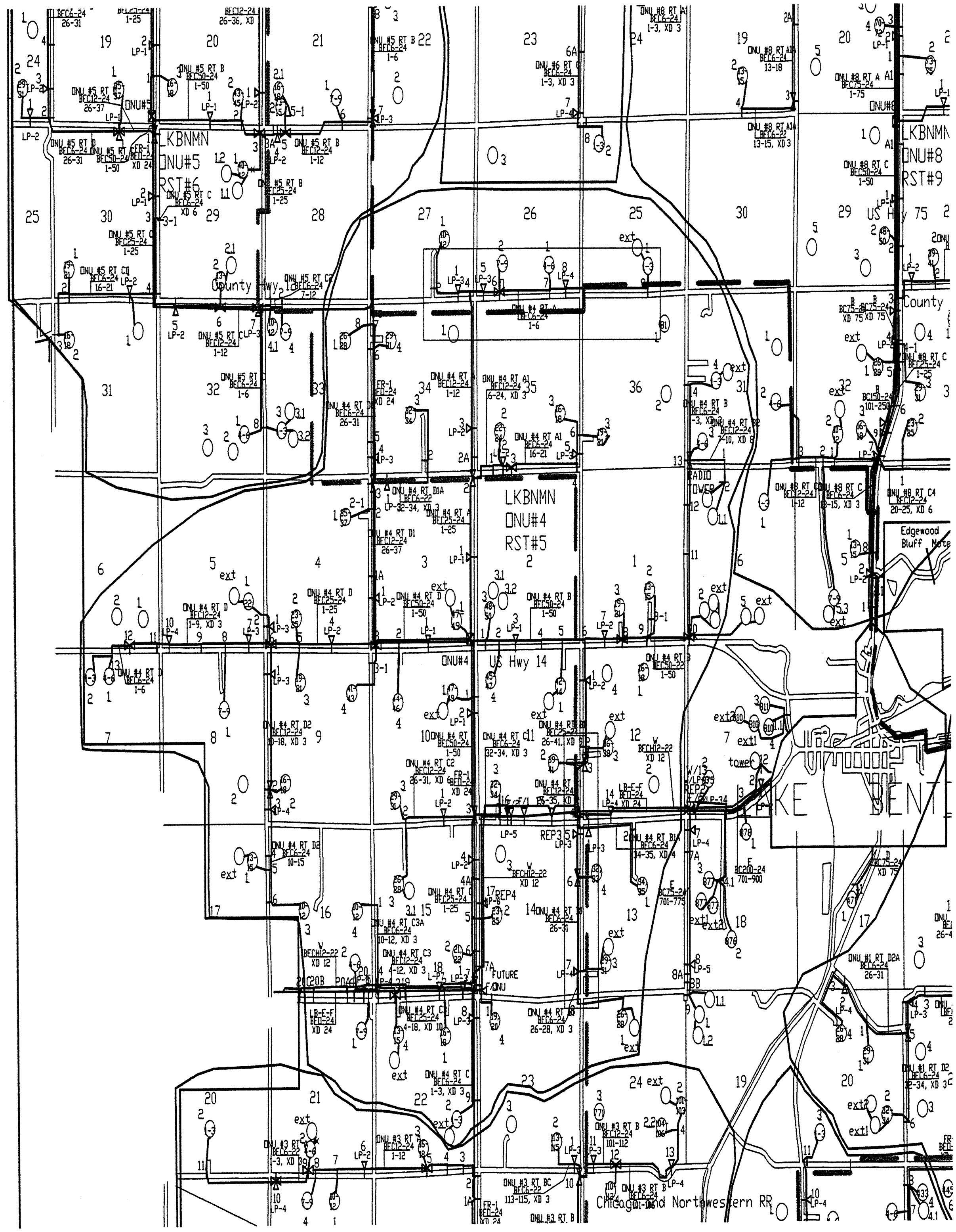

Figure 6

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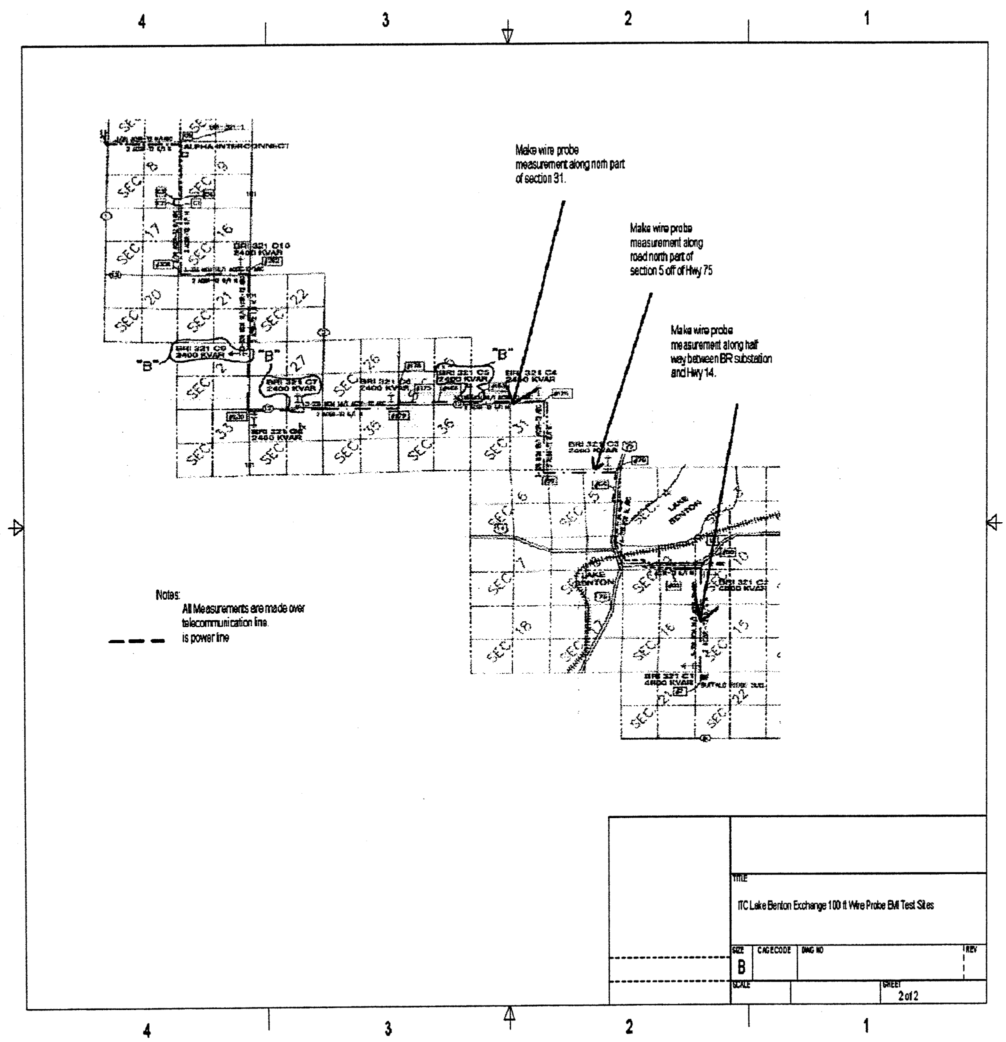

Figure 6 Note: Dotted line is where the feeders run to the points of Interconnection

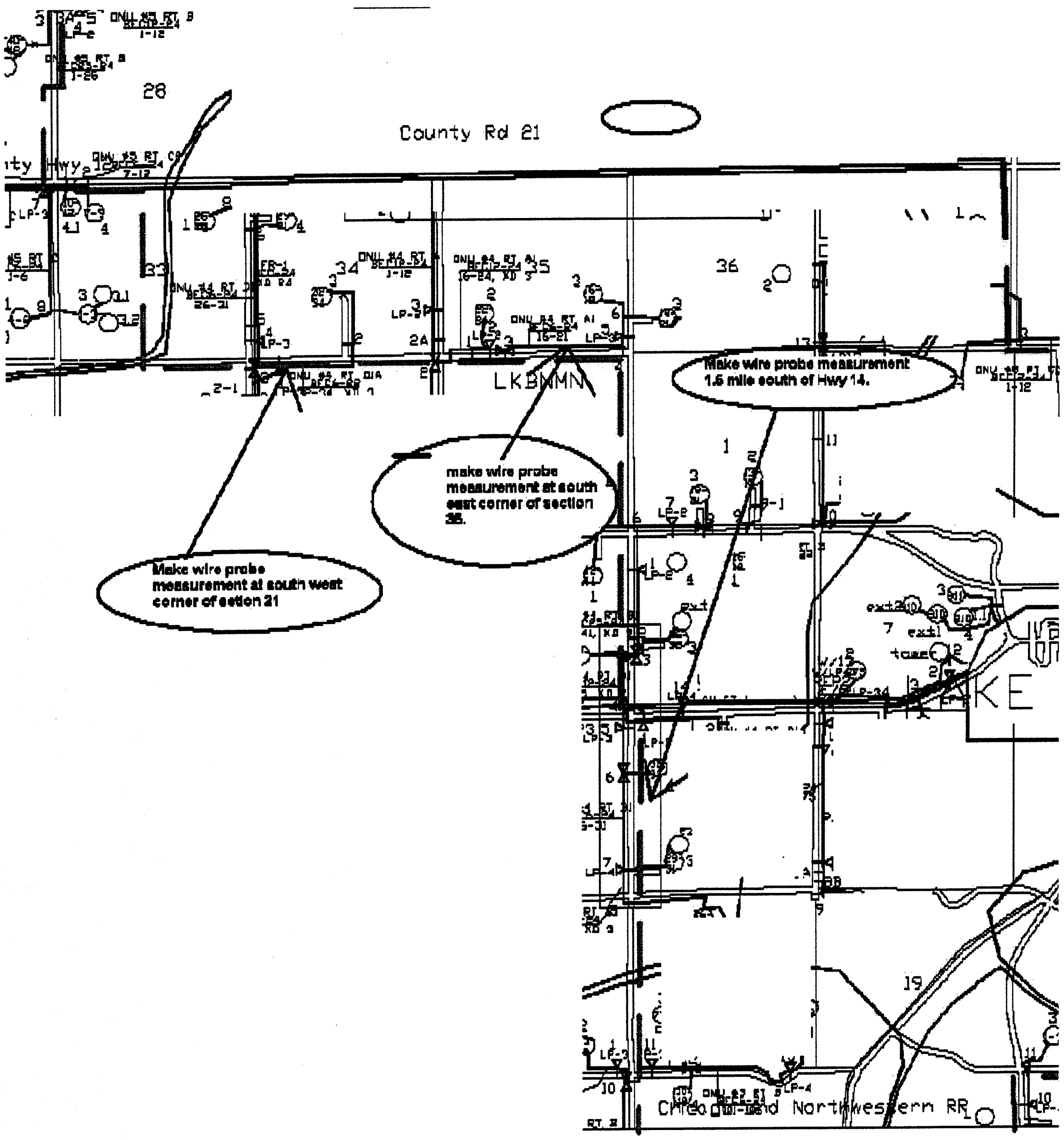
County Rd 21
28
33
34
35
36
LKBNMN
Make wire probe measurement 1.6 mile south of Hwy 14.
make wire probe measurement at south east corner of section 35.
Make wire probe measurement at south west corner of ection 21
19

Figure 7

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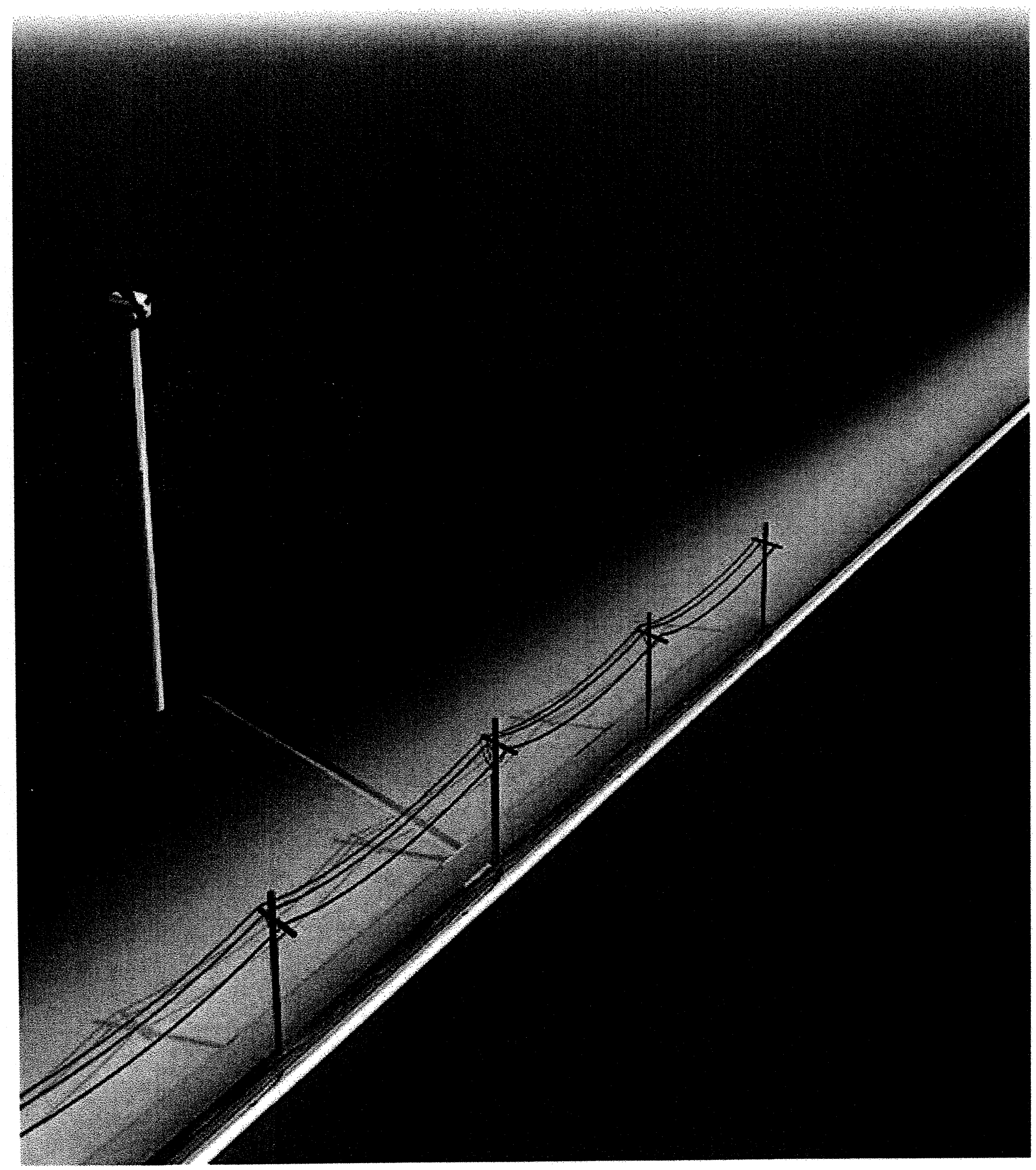
Test Data and Analysis Section 5

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Modified Probe Wire Test, Section 5



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Background

Probe wire voltage/current tests along with voice-pair voltage tests were conducted within the Lake Benton area by personell from "Energy Maintence Service" located in Gary, South Dakota at the direction of "Wilkins Consulting" located in Tehachapi, California, for the purpose of determining the cause(s) of the telecommunication interferance experieced by ITC customers. Wilkins Consulting has created this Mathcad(tm) calculation sheet to take the data aquired by EMS and compare it to relevent IEEE standards.

The standard the data is compared to is IEEE776 titled "IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines." The scope of the standard addresses the inductive environment that exists in the vicinity of electric power and wire-line telecommunication systems and the interfering effect that may be produced. As taken from the standard "Inductive Interferance is defined as an effect, arising from the characteristics and inductive relations of electric supply and telecommunication systems. It is of such character and magnitude that it would prevent the telecommunication circuits from rendering service satisfactorily and economicaly if methods of inductive coordination were not applied". This sheet uses methods givin in this standard to determine the amount of inductive influence the power system has on the telecommunication system.

This sheet uses voltage/current measurements aquired from a modified probe wire test underneath 34.5 kV power lines located near Lake Benton, Minnesota, along with the calculated mutual impeadance between the the overhead conductors and the probe wire to predice the interfering current from the overhead conductors and the induced voltage on Interstate Telecommunication Coorperative's telecommunication lines. This is then compared to the actual voltages measured on the telecommunication line. The methods used to perfrom the calcualtions are based on procedures given by the Institute of Electronic and Electrical Engineers(IEEE) standards 776 and 367. However, some of the test parameters were changed so that the maximum influence over the phone cable could be assesed. For example, a 16 guage wire was used instead of a 22 gauge and the mesurements were made directly over the telecommunication line. Since this is the case the mutual impeadace will be used to project the voltage leves for an interface at a radial distance of 50 feet from the geometric mean of the phase conductors. Once this value is determined it will be compred to the "C message wieghted values" given in IEEE 776 to see if the interferance from the overhead conductors exceed recommended values given.

The instrument used to make such measuremtns is a Tektronics(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1x probe was used to measure the voltage and a standard Tektronix amp clamp probe was used to measure the current. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintance Service. Wilkins Consulting exported the data out of Wavestare to a standard text file. The data was formated in text and laid out in comma seperated values. The data was then imported into a Mathacad work sheet for analysis. This is that sheet.

Probe Wire Measurement Setup:

As taken from IEEE 776 section 4.2.4 the probe wire measuremnt was accomplished by putting two stakes into the ground directly over the telecommunication line and parallel to both the power and telecommunications lines.(Note: The stakes were placed into the ground 24 in)

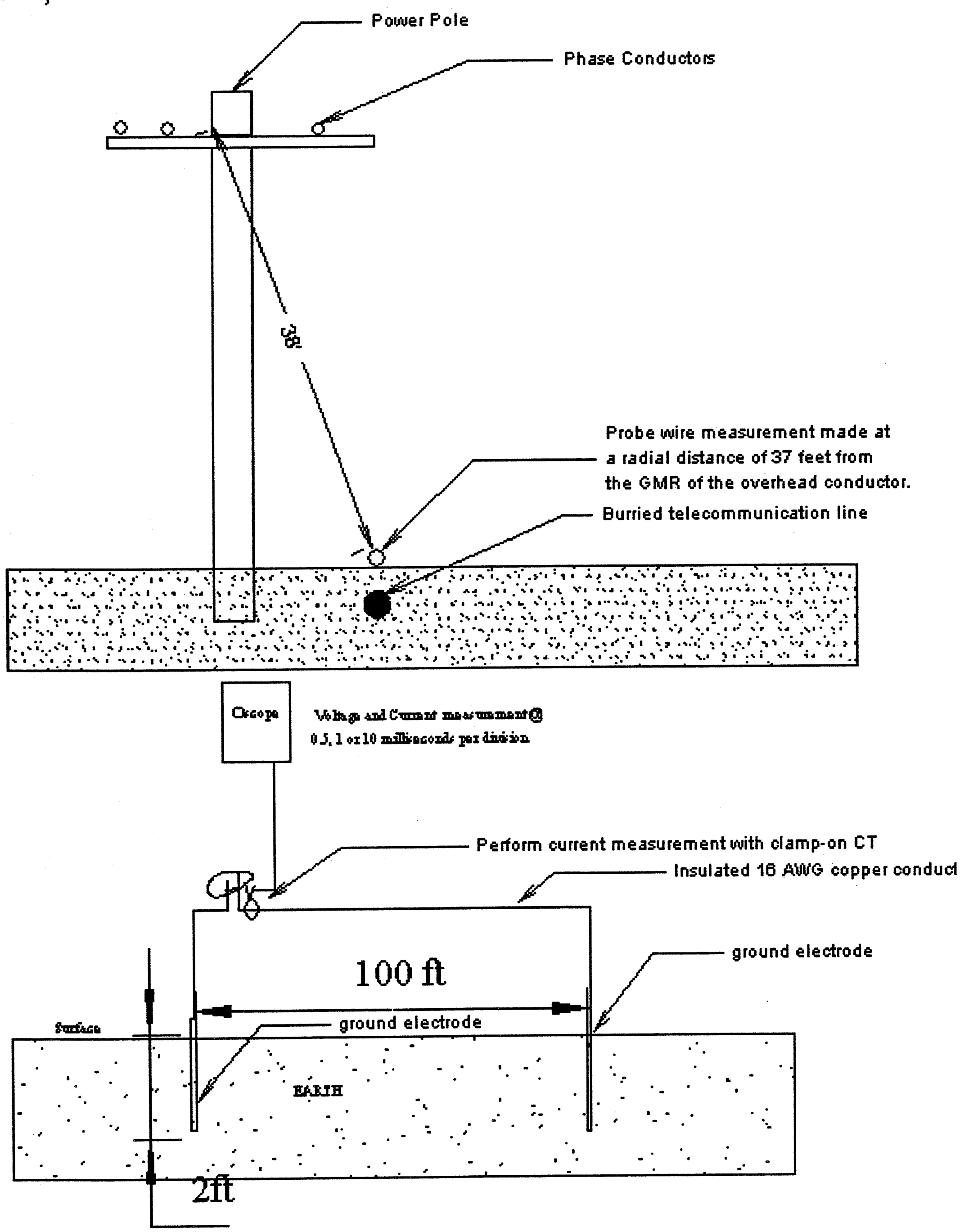

Figure 1A
Figure 1B

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Mutual Impeadance

The mutual Impeadance allows us to project the interfering voltage on the telecommunication line as well as to estime the interfering current on the power lines. The mutual impedance between each conductor is calculated by estimating the soil resistivelty, the geometrical and electromagnetic relationships. In the calculations that follow, the mutual impedance between the disturbing and the disturbed circuits is determined. Since the lines under consideration are parallel, the total exposure is easily determined. The method used to calculate the mutual impeadance will ignore phase change since not of the run pass through transposed sections. Formulation for calculating the external mutual impedance of parallel supply and telecommunication circuits was developed by J. R. Carson Reverence [B9] or IEEE 367. The general configuration for mutual impedance is shown in Figure 2.

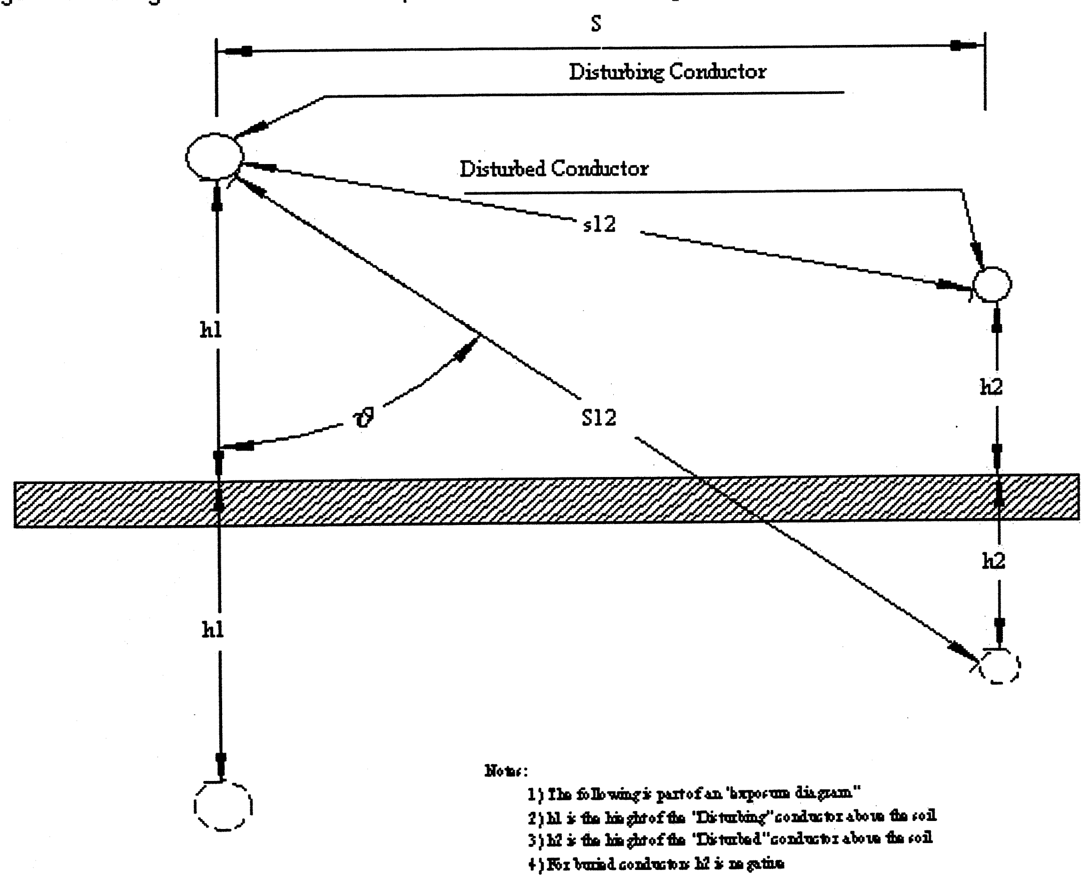

Figure 2

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Shield Factor

The electromagnetically induced voltage measured by the probe wire is the voltage induced in an unshielded telecommunication line. A shield factor is used to take into account the shielding action of all grounded conductors (overhead ground wires, rails, metallic pipes), including metallic sheaths of telecommunication cables, etc., in an inductive exposure. The shield factor used for this study is a combination of the overhead ground wire and the aluminum tape that surrounds the telecommunication cable conductors. Taken from tables 6 and 7 in IEEE 367 the shield factor used is 1. The shield factor is not included so that worst case values can be shown. However a coorective shield factor for each section will be given.

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. Zm1 is the mutual impedance between the probewire and the imaginary conductor that makes up the interfering current

$\text{Exposure} := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$h2 := -0.61$

(4)

$h1 := 11$

(5)

$S := 1$

(6)

$$\sigma := \frac{1}{100}$$

(7)

$\omega_n := 2 \cdot \pi \cdot f_n$

(8)

$$\gamma_n := \left[(j) \cdot \omega_n \cdot 4 \cdot \pi \cdot 10^{-7} \cdot \sigma \right]^{\frac{1}{2}}$$

(9)

$$D0 := \left[\left(S^2\right) + (h1 - h2)^2 \right]^{0.5}$$

(10)

$$D1_n := \left[\left(S^2\right) + \left(h1 + h2 + \frac{2}{\gamma_n}\right)^2 \right]^{0.5}$$

(11)

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$$Zm1_n := Exposure \cdot 3 \cdot j \cdot \omega_n \cdot \left(\frac{4\,\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{(D1_n)}{D0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n \cdot D1_n}\right)^4\right]$$

(12)

$$\theta1_n := \left(\frac{180}{\pi}\right)\,\mathrm{atan}\left(\left(\frac{\mathrm{Im}(Zm1_n)}{\mathrm{Re}(Zm1_n)}\right)\right)$$

(13)

Where:

Equation 1 is the parallel exposure in the section under question
Equation 2 is the the harmonic number
Equation 3 is the coorsponding frequency of the nth harmonic
Equation 4 is the depth of the buried cable is meters
Equation 5 is the hieght of the power line
Equation 6 is the geometric mean horizontal separation of the conductors
Equation 7 is the conductivety of the soil
Equation 8 is the radian frequency of the nth harmonic
Equation 9 is the related to the complex progation constant
Equation 10 D0 is the distance between the two conductors
Equation 11 D1 is the distance between the offending conductor and the image of the disturbed conductor.
Equation 12 Zm is the Mutual Impedance. Note: The 3 multiplier is there for the three phase conductors.
Equation 13 $\theta(n)$ is the angle of the mutual impeadance

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. ZM2 is the mutual impedance betwwen the imaginary conductor that carries the interfering current and the interface.

$Exposure := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$hl2 := 0$

(4)

$hl1 := 10$

(5)

$SI := 16$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2\cdot\pi\cdot f_n$

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(8)

$$\gamma_n := \left[(j)\cdot\omega_n\cdot 4\cdot\pi\cdot 10^{-7}\cdot\sigma\right]^{\frac{1}{2}}$$

(9)

$$DI0 := \left[\left(SI^2\right) + (hI1 - hI2)^2\right]^{0.5}$$

(10)

$$DI1_n := \left[\left(SI^2\right) + \left(hI1 + hI2 + \frac{2}{\gamma_n}\right)^2\right]^{0.5}$$

(11)

$$Zm2_n := Exposure\cdot 3\cdot j\cdot\omega_n\cdot\left(\frac{4\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{\left(DI1_n\right)}{DI0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n\cdot DI1_n}\right)^4\right]$$

(12)

$$\theta 2_n := \left(\frac{180}{\pi}\right)\cdot atan\left(\left(\frac{Im\left(Zm2_n\right)}{Re\left(Zm2_n\right)}\right)\right)$$

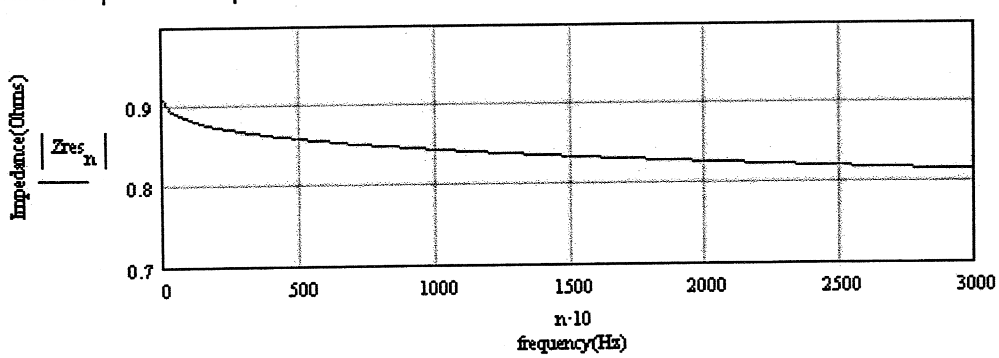
(13)

(14)

$$Zres_n := \frac{Zm2_n}{Zm1_n}$$

Mutual Impeadance for the Interface

In order to compare the measured voltage levels on the probe wire the need to project to a radial of distance of 50 feet. This is accomplished by computing the complex mutual impedance ratio and multiplying it by the probe wire voltage Equation 14 shows the relationship for the impedance labled Zres.



Measured Probe Wire Voltage

The following tables and graphs are created from data aquired by the Tectronics(tm) O-scope. The data was put into tablular format and imported into Mathcad for analysis.

DCoffset := - 0.018

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table :=

	0	1
0	0	0
1	-0.05	0.028
2	-0.04996	0.03
3	-0.04992	0.04
4	-0.04988	0.04
5	-0.04984	0.052
6	-0.0498	0.046
7	-0.04976	0.056
8	-0.04972	0.058
9	-0.04968	0.058

$\text{time} := \text{table}^{\langle 0 \rangle}$

$\text{Volts} := \text{DCoffset} + \left[(10 \cdot \text{table})^{\langle 1 \rangle}\right]$

Time domain data from the "probe wire measurement" was exported from wavestar(tm) and imported into mathcad via the above input table.

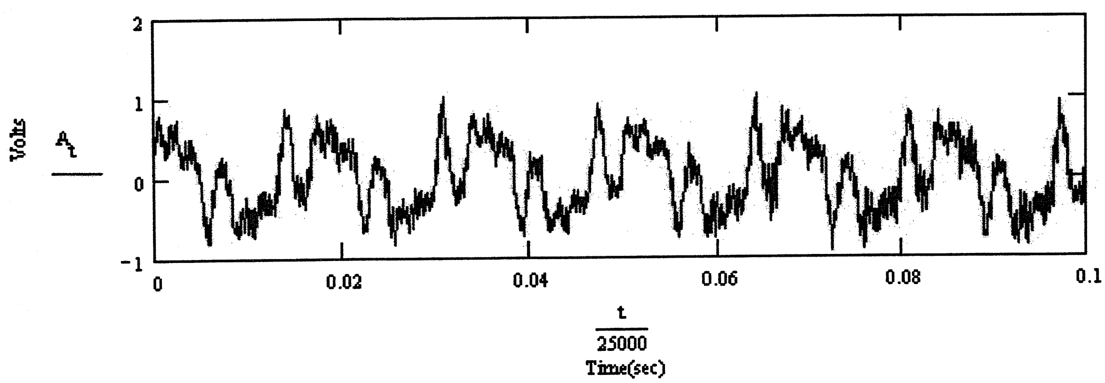
$$\frac{1}{0.049960 - 0.049920} = 2.5 \cdot 10^{4}$$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a fourier transform of a 2^{m}-element vector of real data measured at regularly spaced points in time.

$t := 0 .. 2499$

$A_t := \text{Volts}_t$



Take Fourier transform:

$c := \text{CFFT}(\text{Volts})$

$N := \text{last}(c)$

$N := 2499$

Complex frequency vector

$j := -0 .. N$

$\text{Vres}_j := c_j \cdot \text{Zres}_j$

The voltage in frequency domain is multipled by Zres to determine the interface voltage.

Probe Wire Measurement Frequency Domain(60 to 10kHz)

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Thresholds

From IEEE 776 the harmonic threshold for greater than 3 harmonics in the range of 2 to 17 is given by equation 15 below. From IEEE 776 the harmonic threshhold for greater than 3 harmonics in the range of 18 to 50 is given in equation 16 below. VP is the 60 Hz voltage for the zone 1. Refer to IEEE 776 for definitions. Vdl is the lower order harmonic voltage threshold limit, Vdh is the higher order larmonic voltage threshold limit.

$n1 := 1 .. 102$

n1 is the index factor for calculating the harmonic threshhold below 1020 hz(17th harmonic).

$Vp := 0.333$

$$Vdl_{n1} := Vp \cdot \left(\frac{n1}{6}\right)^{-2.7}$$

(15)

Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 60 Hz and 1000 Hz.

n2 is the index factor for calculating the harmonic threshhold above 1080 hz(18th harmonic) to 3000 hz(50th harmonic).

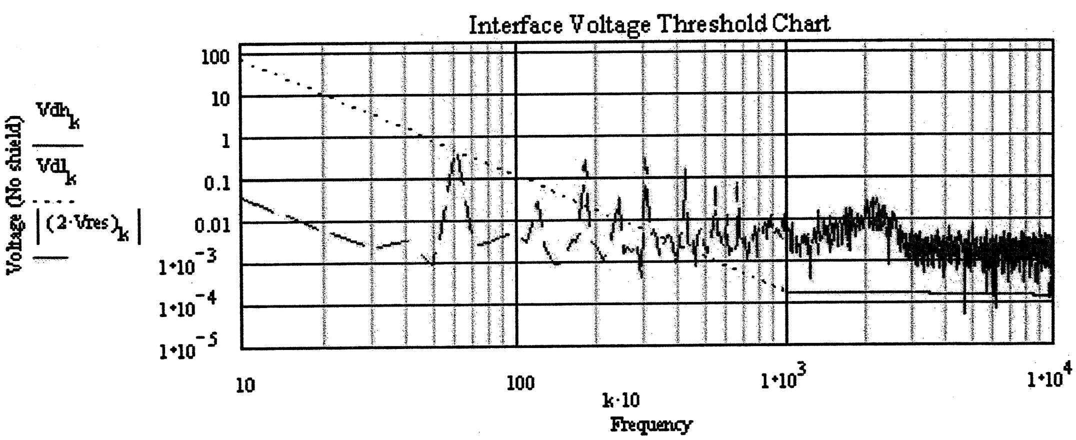
$n2 := 102 .. 2499$

$$Vdh_{n2} := Vp \cdot \frac{1}{17^{2.7} + \left(\frac{n2}{6}\right)^{1.2}}$$

(16)

Where Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 1020 Hz and 3000 Hz. Given below is the voltage threshold chart. The chart compares the projected probe wire voltage levels to the threshold values given in IEEE776.

$k := 1 .. 2499$



The tabulated data given below shows the how much the probe wire threshold voltage is or is not exceeded for a given frequency from the zone 1 values given in IEEE 776. Note these values are normalized to 1kM.

$$Vover_{n1} := -Vdl_{n1} + \left| 1.2 \cdot Vres_{n1} \right|$$

$$Vover_{n2} := -Vdh_{n2} + \left| 1.2 \cdot Vres_{n2} \right|$$

$x := 1 .. 50$

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$Vover_{x\cdot 6} =$

0.042
-0.027
0.188
0.021
0.231
$6.082\cdot 10^{-4}$
0.124
$4.591\cdot 10^{-3}$
0.049
$9.8\cdot 10^{-3}$
0.061
$2.016\cdot 10^{-3}$
$3.288\cdot 10^{-3}$
$5.161\cdot 10^{-3}$
$7.174\cdot 10^{-3}$
$3.666\cdot 10^{-3}$

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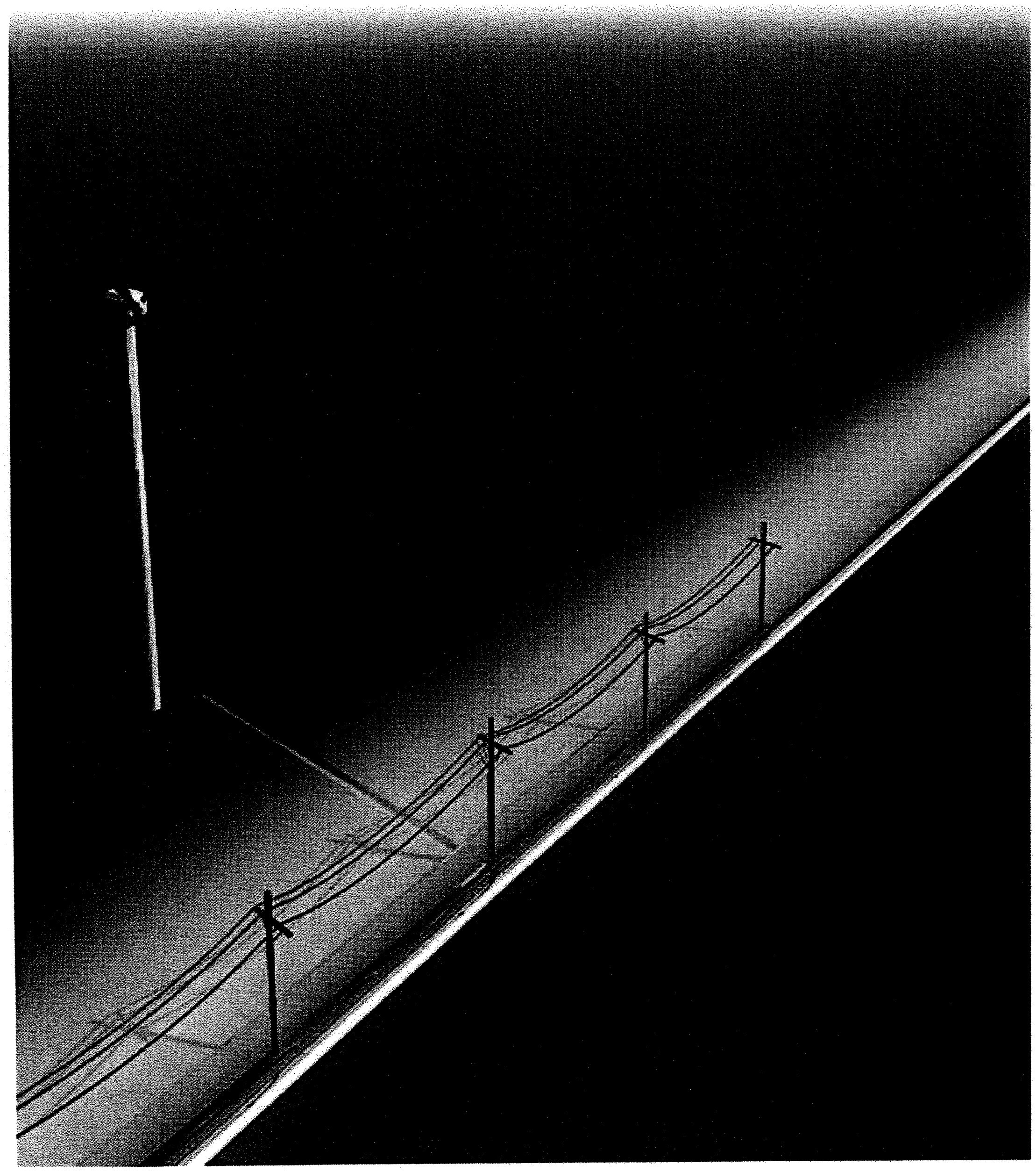
Testing and Analysis Section 12

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Modified Probe Wire Test, Section 12



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Background

Probe wire voltage/current tests along with voice-pair voltage tests were conducted within the Lake Benton area by personell from "Energy Maintence Service" located in Gary, South Dakota at the direction of "Wilkins Consulting" located in Tehachapi, California, for the purpose of determining the cause(s) of the telecommunication interferance experieced by ITC customers. Wilkins Consulting has created this Mathcad(tm) calculation sheet to take the data aquired by EMS and compare it to relevent IEEE standards.

The standard the data is compared to is IEEE776 titled "IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines." The scope of the standard addresses the inductive environment that exists in the vicinity of electric power and wire-line telecommunication systems and the interfering effect that may be produced. As taken from the standard "Inductive Interferance is defined as an effect, arising from the characteristics and inductive relations of electric supply and telecommunication systems. It is of such character and magnitude that it would prevent the telecommunication circuits from rendering service satisfactorily and economicaly if methods of inductive coordination were not applied". This sheet uses methods givin in this standard to determine the amount of inductive influence the power system has on the telecommunication system.

This sheet uses voltage/current measurements aquired from a modified probe wire test underneath 34.5 kV power lines located near Lake Benton, Minnesota, along with the calculated mutual impeadance between the the overhead conductors and the probe wire to predice the interfering current from the overhead conductors and the induced voltage on Interstate Telecommunication Coorperative's telecommunication lines. This is then compared to the actual voltages measured on the telecommunication line. The methods used to perfrom the calcualtions are based on procedures given by the Institute of Electronic and Electrical Engineers(IEEE) standards 776 and 367. However, some of the test parameters were changed so that the maximum influence over the phone cable could be assesed. For example, a 16 guage wire was used instead of a 22 gauge and the mesurements were made directly over the telecommunication line. Since this is the case the mutual impeadace will be used to project the voltage leves for an interface at a radial distance of 50 feet from the geometric mean of the phase conductors. Once this value is determined it will be compred to the "C message wieghted values" given in IEEE 776 to see if the interferance from the overhead conductors exceed recommended values given.

The instrument used to make such measuremtns is a Tektronics(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1x probe was used to measure the voltage and a standard Tektronix amp clamp probe was used to measure the current. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintance Service. Wilkins Consulting exported the data out of Wavestare to a standard text file. The data was formated in text and laid out in comma seperated values. The data was then imported into a Mathacad work sheet for analysis. This is that sheet.

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Probe Wire Measurement Setup:

As taken from IEEE 776 section 4.2.4 the probe wire measuremnt was accomplished by putting two stakes into the ground directly over the telecommunication line and parallel to both the power and telecommunications lines.(Note: The stakes were placed into the ground 24 in)

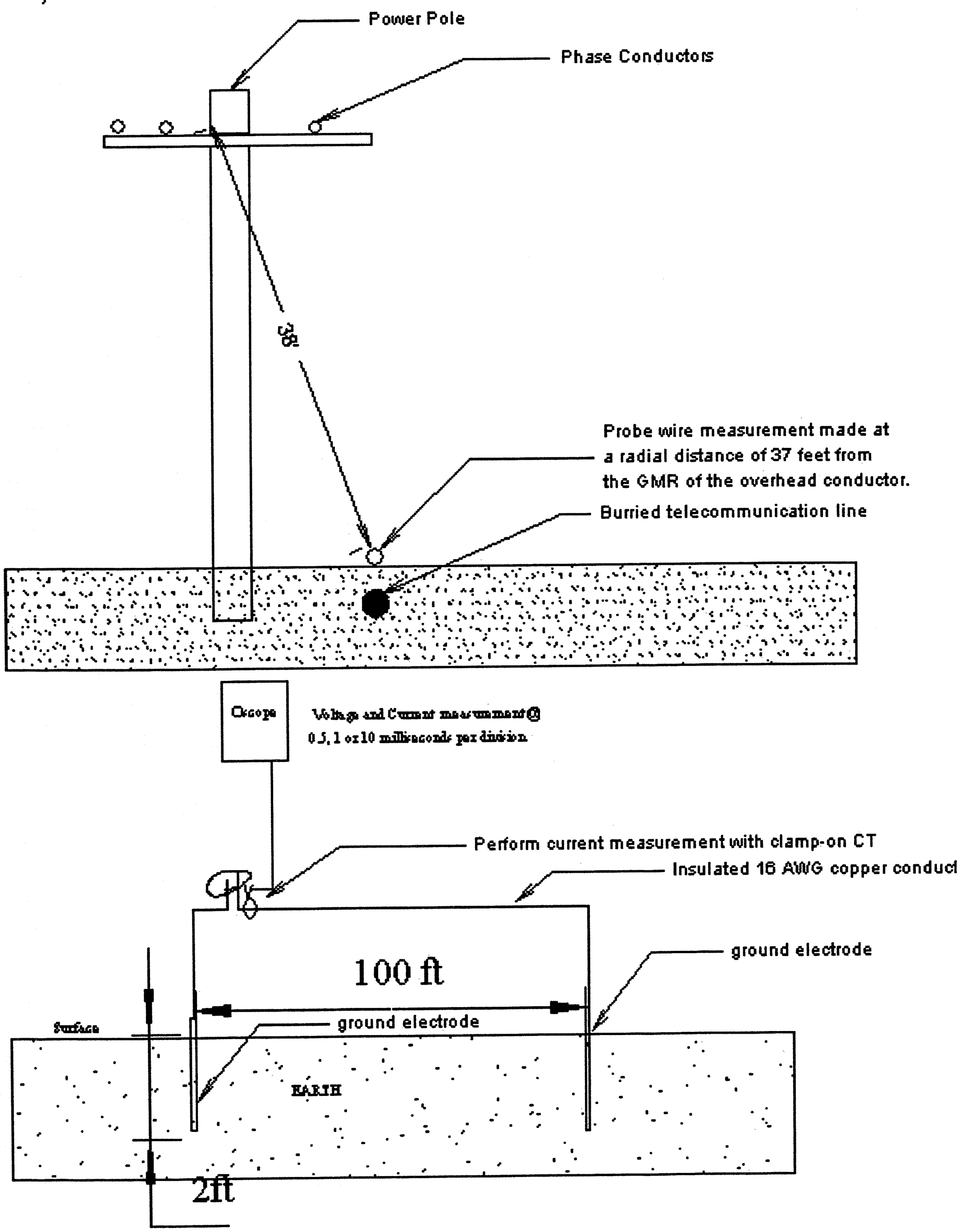

Figure 1A
Figure 1B

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Mutual Impeadance

The mutual Impeadance allows us to project the interfering voltage on the telecommunication line as well as to estime the interfering current on the power lines. The mutual impedance between each conductor is calculated by estimating the soil resistivelty, the geometrical and electromagnetic relationships. In the calculations that follow, the mutual impedance between the disturbing and the disturbed circuits is determined. Since the lines under consideration are parallel, the total exposure is easily determined. The method used to calculate the mutual impeadance will ignore phase change since not of the run pass through transposed sections. Formulation for calculating the external mutual impedance of parallel supply and telecommunication circuits was developed by J. R. Carson Reverence [B9] or IEEE 367. The general configuration for mutual impedance is shown in Figure 2.

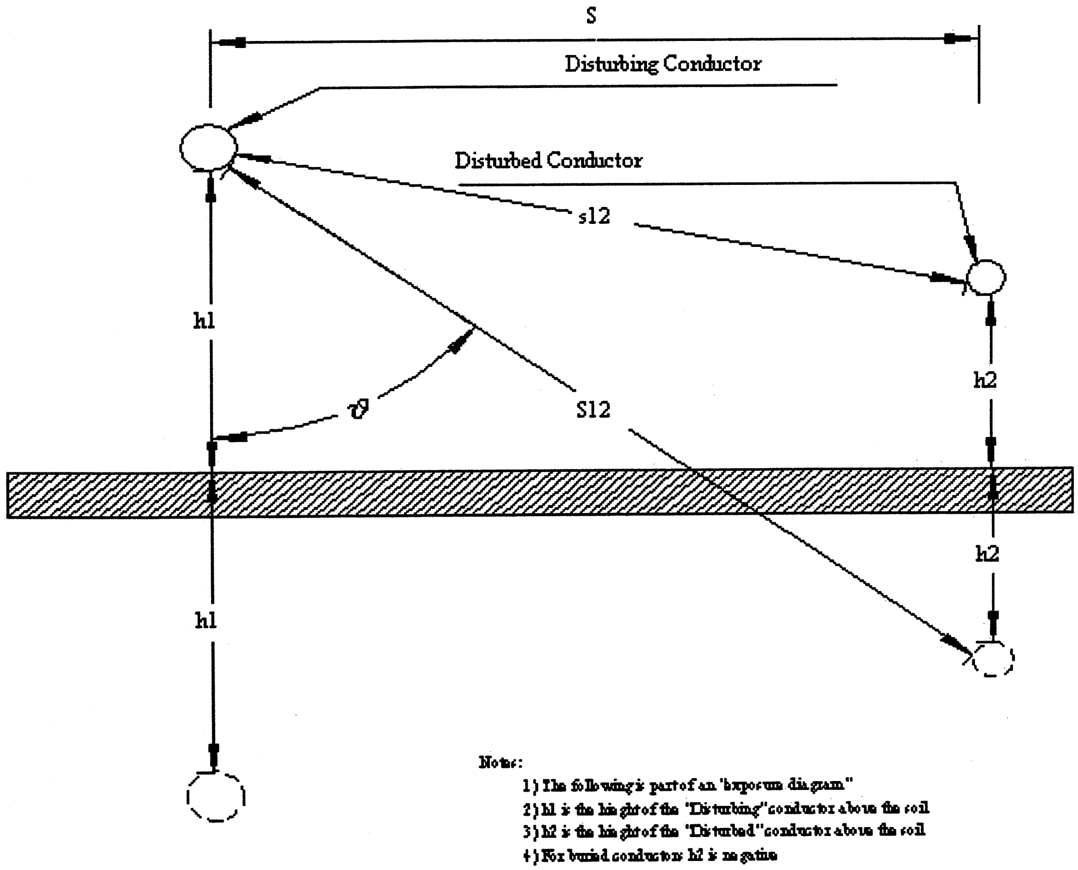

Figure 2

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Shield Factor

The electromagnetically induced voltage measured by the probe wire is the voltage induced in an unshielded telecommunication line. A shield factor is used to take into account the shielding action of all grounded conductors (overhead ground wires, rails, metallic pipes), including metallic sheaths of telecommunication cables, etc., in an inductive exposure. The shield factor used for this study is a combination of the overhead ground wire and the aluminum tape that surrounds the telecommunication cable conductors. Taken from tables 6 and 7 in IEEE 367 the shield factor used is 1. The shield factor is not included so that worst case values can be shown. However a coorective shield factor for each section will be given.

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. Zm1 is the mutual impedance between the probewire and the imaginary conductor that makes up the interfering current

$\text{Exposure} := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$h2 := -0.61$

(4)

$h1 := 11$

(5)

$S := 1$

(6)

$\sigma := \dfrac{1}{100}$

(7)

$\omega_n := 2 \cdot \pi \cdot f_n$

(8)

$$\gamma_n := \left[(j) \cdot \omega_n \cdot 4 \cdot \pi \cdot 10^{-7} \cdot \sigma \right]^{\frac{1}{2}}$$

(9)

$$D0 := \left[\left(S^2\right) + (h1 - h2)^2 \right]^{0.5}$$

(10)

$$D1_n := \left[\left(S^2\right) + \left(h1 + h2 + \frac{2}{\gamma_n}\right)^2 \right]^{0.5}$$

(11)

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$$Zm1_n := Exposure\cdot 3\cdot j\cdot\omega_n\cdot\left(\frac{4\,\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{\left(D1_n\right)}{D0}\right]-\frac{1}{12}\cdot\left(\frac{2}{\gamma_n\cdot D1_n}\right)^4\right]$$

(12)

$$\theta 1_n := \left(\frac{180}{\pi}\right)\cdot\operatorname{atan}\left(\left(\frac{\operatorname{Im}\left(Zm1_n\right)}{\operatorname{Re}\left(Zm1_n\right)}\right)\right)$$

(13)

Where: Equation 1 is the parallel exposure in the section under question
Equation 2 is the the harmonic number
Equation 3 is the coorsponding frequency of the nth harmonic
Equation 4 is the depth of the buried cable is meters
Equation 5 is the hieght of the power line
Equation 6 is the geometric mean horizontal separation of the conductors
Equation 7 is the conductivety of the soil
Equation 8 is the radian frequency of the nth harmonic
Equation 9 is the related to the complex progation constant
Equation 10 D0 is the distance between the two conductors
Equation 11 D1 is the distance between the offending conductor and the image of the disturbed conductor.
Equation 12 Zm is the Mutual Impedance. Note: The 3 multiplier is there for the three phase conductors.
Equation 13 $\theta(n)$ is the angle of the mutual impeadance

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. ZM2 is the mutual impedance betwwen the imaginary conductor that carries the interfering current and the interface.

$Exposure := 1$

(1)

$n := 1..2500$

(2)

$f_n := 10\cdot n$

(3)

$hI2 := 0$

(4)

$hI1 := 10$

(5)

$SI := 16$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2\cdot\pi\cdot f_n$

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(8)

$$\gamma_n := \left[(j)\cdot\omega_n\cdot 4\cdot\pi\cdot 10^{-7}\cdot\sigma\right]^{\frac{1}{2}}$$

(9)

$$DI0 := \left[\left(SI^2\right) + (hI1 - hI2)^2\right]^{0.5}$$

(10)

$$DI1_n := \left[\left(SI^2\right) + \left(hI1 + hI2 + \frac{2}{\gamma_n}\right)^2\right]^{0.5}$$

(11)

$$Zm2_n := Exposure\cdot 3\cdot j\cdot\omega_n\cdot\left(\frac{4\,\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{\left(DI1_n\right)}{DI0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n\cdot DI1_n}\right)^4\right]$$

(12)

$$\theta 2_n := \left(\frac{180}{\pi}\right)\,\mathrm{atan}\left(\left(\frac{\mathrm{Im}\left(Zm2_n\right)}{\mathrm{Re}\left(Zm2_n\right)}\right)\right)$$

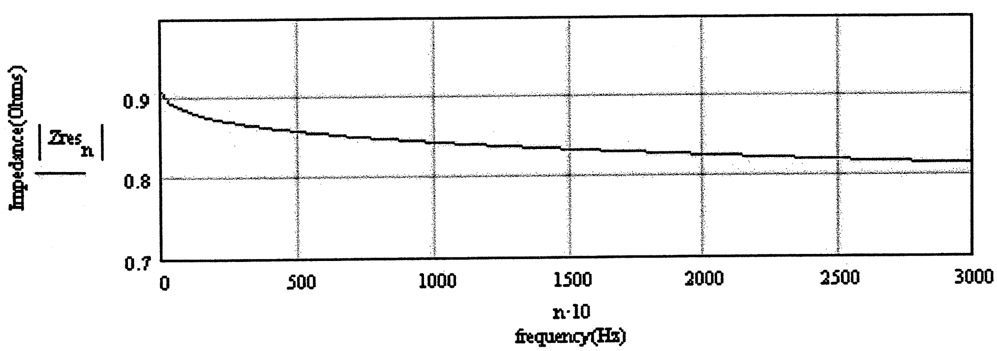
(13)

(14)

$$Zres_n := \frac{Zm2_n}{Zm1_n}$$

Mutual Impeadance for the Interface

In order to compare the measured voltage levels on the probe wire the need to project to a radial of distance of 50 feet. This is accomplished by computing the complex mutual impedance ratio and multiplying it by the probe wire voltage Equation 14 shows the relationship for the impedance labled Zres.



Measured Probe Wire Voltage

The following tables and graphs are created from data aquired by the Tectronics(tm) O-scope. The data was put into tablular format and imported into Mathcad for analysis.

DCoffset := -0.018

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table :=

	0	1
0	0	0
1	-0.05	0.05
2	-0.04996	0.042
3	-0.04992	0.048
4	-0.04988	0.06
5	-0.04984	0.052
6	-0.0498	0.068
7	-0.04976	0.068
8	-0.04972	0.056
9	-0.04968	0.074
10	[illegible]	[illegible]

$time := table^{\langle 0 \rangle}$

$Volts := DCoffset + \left[(10 \cdot table)^{\langle 1 \rangle} \right]$

Time domain data from the "probe wire measurement" was exported from wavestar(tm) and imported into mathcad via the above input table.

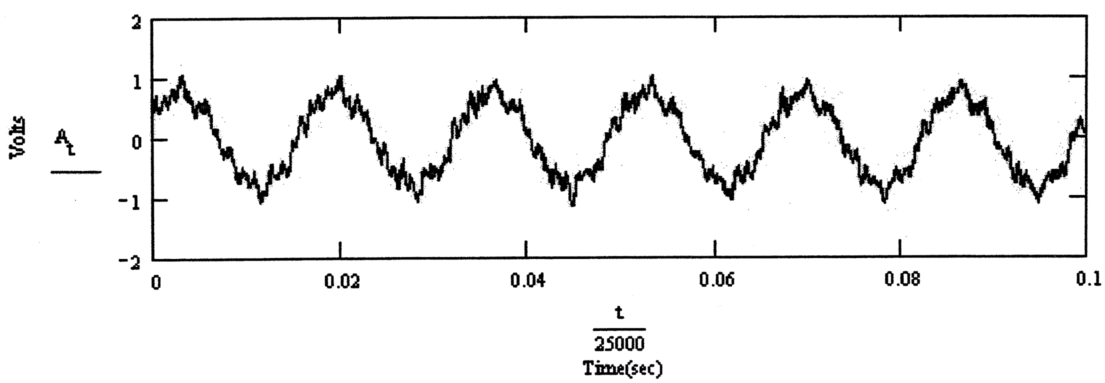
$\frac{1}{0.049960 - 0.049920} = 2.5 \cdot 10^4$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0 .. 2499$

$A_t := Volts_t$



Take Fourier transform:

$c := CFFT(Volts)$

$N := last(c)$

$N := 2499$

Complex frequency vector

$j := -0 .. N$

$Vres_j := c_j \cdot Zres_j$

The voltage in frequency domain is multipled by Zres to determine the interface voltage.

Probe Wire Measurement Frequency Domain(60 to 10kHz)

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Thresholds

From IEEE 776 the harmonic threshold for greater than 3 harmonics in the range of 2 to 17 is given by equation 15 below. From IEEE 776 the harmonic threshhold for greater than 3 harmonics in the range of 18 to 50 is given in equation 16 below. VP is the 60 Hz voltage for the zone 1. Refer to IEEE 776 for definitions. Vdl is the lower order harmonic voltage threshold limit, Vdh is the higher order larmonic voltage threshold limit.

$n1 := 1..102$

n1 is the index factor for calculating the harmonic threshhold below 1020 hz(17th harmonic).

$Vp := 0.333$

$$Vdl_{n1} := Vp \cdot \left(\frac{n1}{6}\right)^{-2.7}$$

(15)

Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 60 Hz and 1000 Hz.

n2 is the index factor for calculating the harmonic threshhold above 1080 hz(18th harmonic) to 3000 hz(50th harmonic).

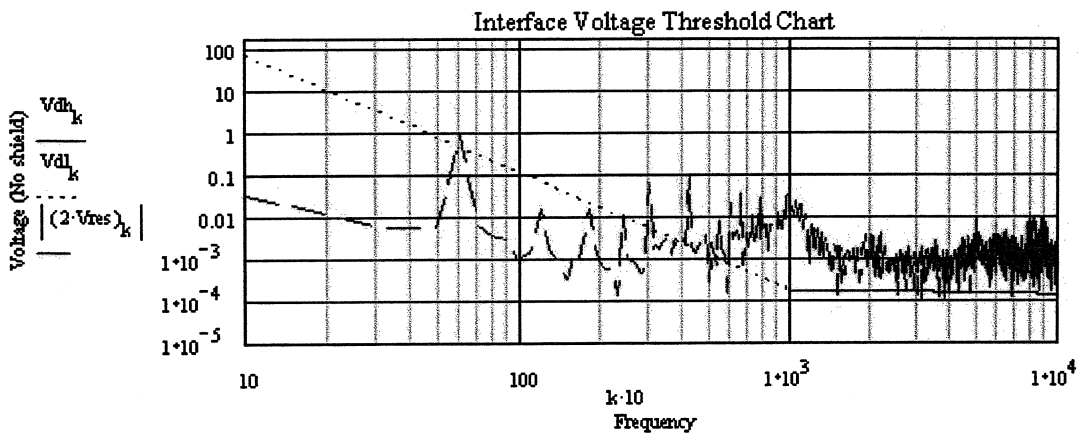
$n2 := 102..2499$

$$Vdh_{n2} := Vp \cdot \frac{1}{17^{2.7} + \left(\frac{n2}{6}\right)^{1.2}}$$

(16)

Where Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 1020 Hz and 3000 Hz. Given below is the voltage threshold chart. The chart compares the projected probe wire voltage levels to the threshold values given in IEEE776.

$k := 1..2499$



The tabulated data given below shows the how much the probe wire threshold voltage is or is not exceeded for a given frequency from the zone 1 values given in IEEE 776. Note these values are normalized to 1kM.

$Vover_{n1} := -Vdl_{n1} + \left| 1.2 \cdot Vres_{n1} \right|$

$Vover_{n2} := -Vdh_{n2} + \left| 1.2 \cdot Vres_{n2} \right|$

$x := 1..50$

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$Vover_{x \cdot 6} =$

0.377
-0.038
$-4.085 \cdot 10^{-3}$
$1.762 \cdot 10^{-3}$
0.051
$-1.649 \cdot 10^{-3}$
0.07
$2.146 \cdot 10^{-3}$
$6.275 \cdot 10^{-3}$
0.019
0.03
$9.616 \cdot 10^{-3}$
0.024
$5.674 \cdot 10^{-3}$
$3.779 \cdot 10^{-3}$
$4.784 \cdot 10^{-3}$

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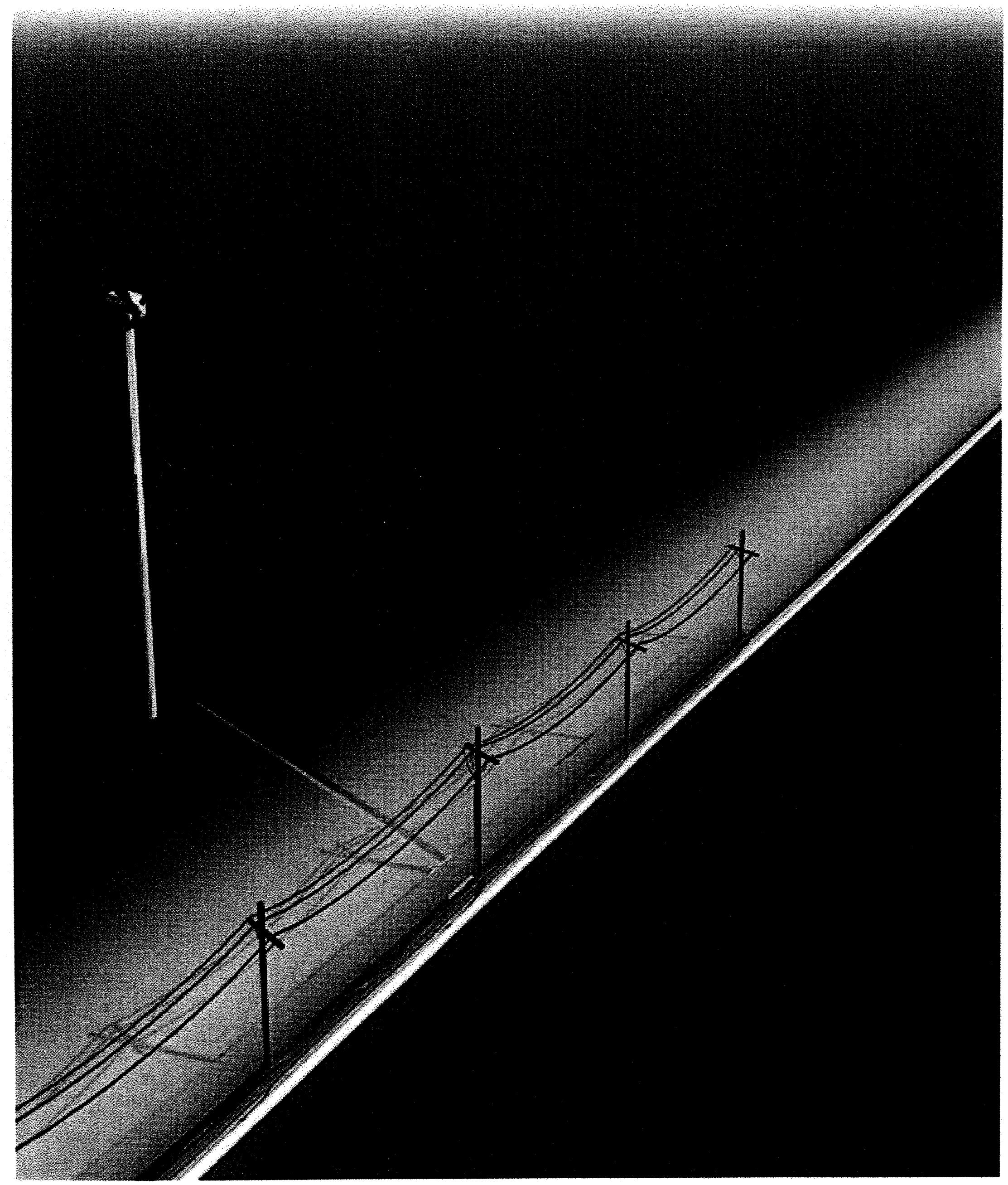
Testing and Analysis Section 15

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Modified Probe Wire Test, Section 15



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The instrument used to make such measuremtns is a Tektronics(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1x probe was used to measure the voltage and a standard Tektronix amp clamp probe was used to measure the current. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintance Service. Wilkins Consulting exported the data out of Wavestare to a standard text file. The data was formated in text and laid out in comma seperated values. The data was then imported into a Mathacad work sheet for analysis. This is that sheet.

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Probe Wire Measurement Setup:

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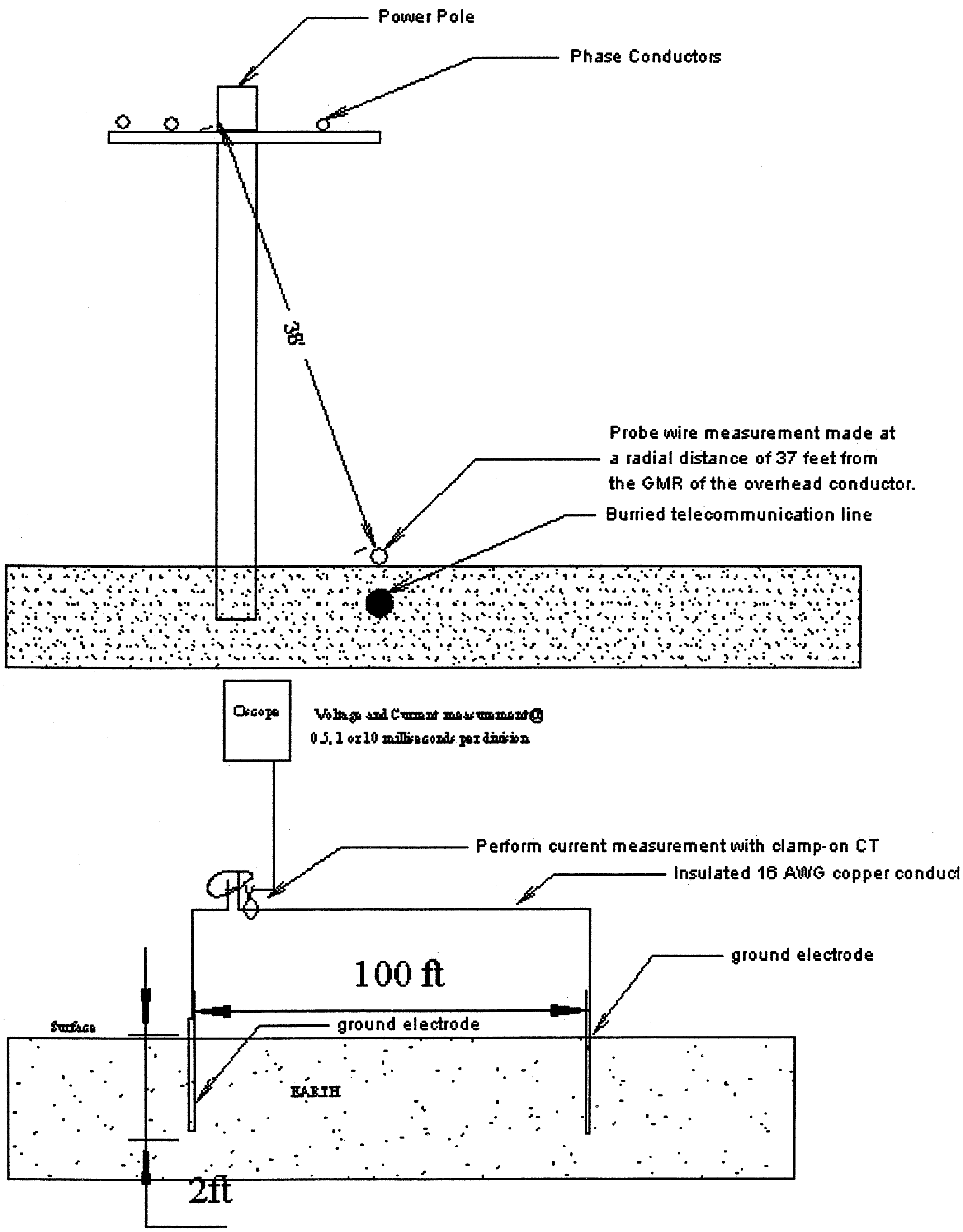

Figure 1A
Figure 1B

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Mutual Impeadance

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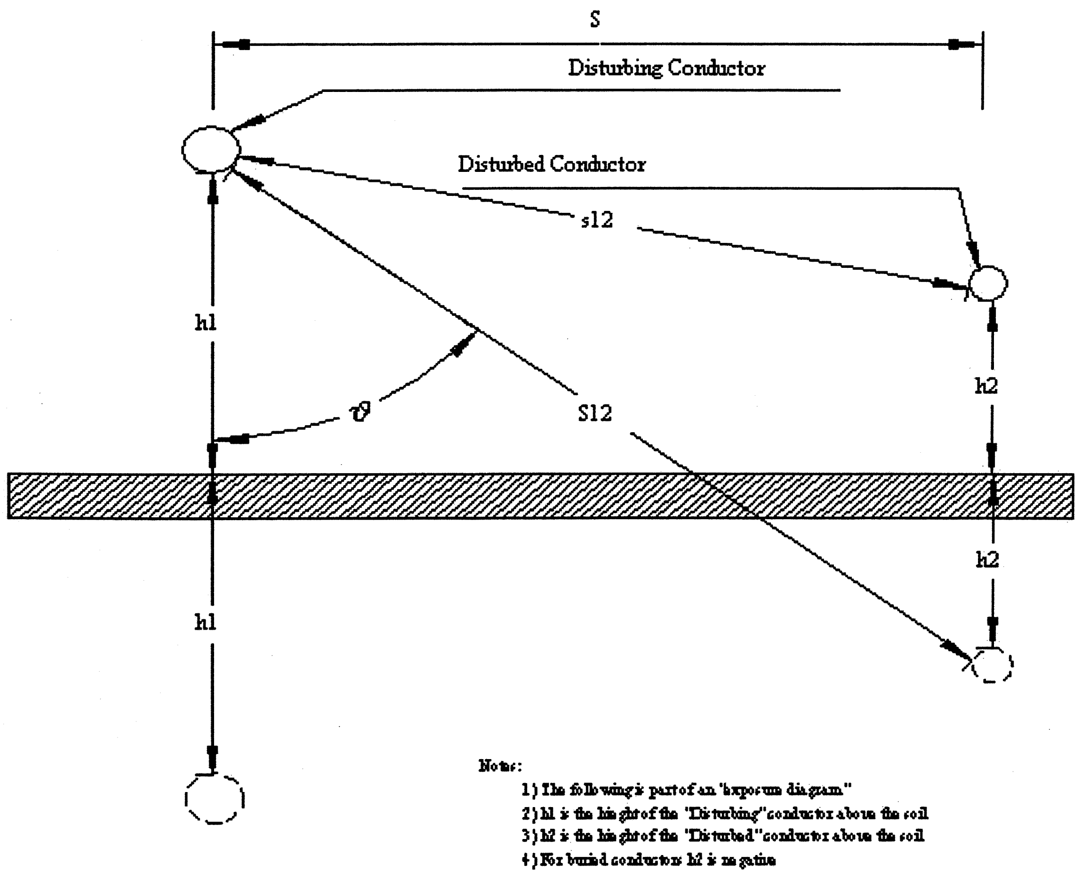

Figure 2

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Shield Factor

The electromagnetically induced voltage measured by the probe wire is the voltage induced in an unshielded telecommunication line. A shield factor is used to take into account the shielding action of all grounded conductors (overhead ground wires, rails, metallic pipes), including metallic sheaths of telecommunication cables, etc., in an inductive exposure. The shield factor used for this study is a combination of the overhead ground wire and the aluminum tape that surrounds the telecommunication cable conductors. Taken from tables 6 and 7 in IEEE 367 the shield factor used is 1. The shield factor is not included so that worst case values can be shown. However a coorective shield factor for each section will be given.

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. Zm1 is the mutual impedance between the probewire and the imaginary conductor that makes up the interfering current

$\text{Exposure} := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$h2 := -0.61$

(4)

$h1 := 11$

(5)

$S := 1$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2 \cdot \pi \cdot f_n$

(8)

$$\gamma_n := \left[(j) \cdot \omega_n \cdot 4 \cdot \pi \cdot 10^{-7} \cdot \sigma \right]^{\frac{1}{2}}$$

(9)

$$D0 := \left[\left(S^2\right) + (h1 - h2)^2 \right]^{0.5}$$

(10)

$$D1_n := \left[\left(S^2\right) + \left(h1 + h2 + \frac{2}{\gamma_n}\right)^2 \right]^{0.5}$$

(11)

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$$Zm1_n := \text{Exposure} \cdot 3 \cdot j \cdot \omega_n \cdot \left(\frac{4\,\pi}{2 \cdot \pi} \cdot 10^{-7}\right) \cdot \left[\ln\left[\frac{(D1_n)}{D0}\right] - \frac{1}{12} \cdot \left(\frac{2}{\gamma_n \cdot D1_n}\right)^4\right]$$

(12)

$$\theta 1_n := \left(\frac{180}{\pi}\right) \text{atan}\left(\left(\frac{\text{Im}(Zm1_n)}{\text{Re}(Zm1_n)}\right)\right)$$

(13)

Where: Equation 1 is the parallel exposure in the section under question
Equation 2 is the the harmonic number
Equation 3 is the coorsponding frequency of the nth harmonic
Equation 4 is the depth of the buried cable is meters
Equation 5 is the hieght of the power line
Equation 6 is the geometric mean horizontal separation of the conductors
Equation 7 is the conductivety of the soil
Equation 8 is the radian frequency of the nth harmonic
Equation 9 is the related to the complex progation constant
Equation 10 D0 is the distance between the two conductors
Equation 11 D1 is the distance between the offending conductor and the image of the disturbed conductor.
Equation 12 Zm is the Mutual Impedance. Note: The 3 multiplier is there for the three phase conductors.
Equation 13 θ(n) is the angle of the mutual impeadance

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. ZM2 is the mutual impedance betwwen the imaginary conductor that carries the interfering current and the interface.

$\text{Exposure} := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$hl2 := 0$

(4)

$hl1 := 10$

(5)

$Sl := 16$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2 \cdot \pi \cdot f_n$

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(8)

$$\gamma_n := \left[(j)\cdot\omega_n\cdot 4\cdot\pi\cdot 10^{-7}\cdot\sigma\right]^{\frac{1}{2}}$$

(9)

$$DI0 := \left[\left(SI^2\right) + (hI1 - hI2)^2\right]^{0.5}$$

(10)

$$DI1_n := \left[\left(SI^2\right) + \left(hI1 + hI2 + \frac{2}{\gamma_n}\right)^2\right]^{0.5}$$

(11)

$$Zm2_n := Exposure\cdot 3\cdot j\cdot\omega_n\cdot\left(\frac{4\,\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{\left(DI1_n\right)}{DI0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n\cdot DI1_n}\right)^4\right]$$

(12)

$$\theta2_n := \left(\frac{180}{\pi}\right)\cdot atan\left(\left(\frac{Im\left(Zm2_n\right)}{Re\left(Zm2_n\right)}\right)\right)$$

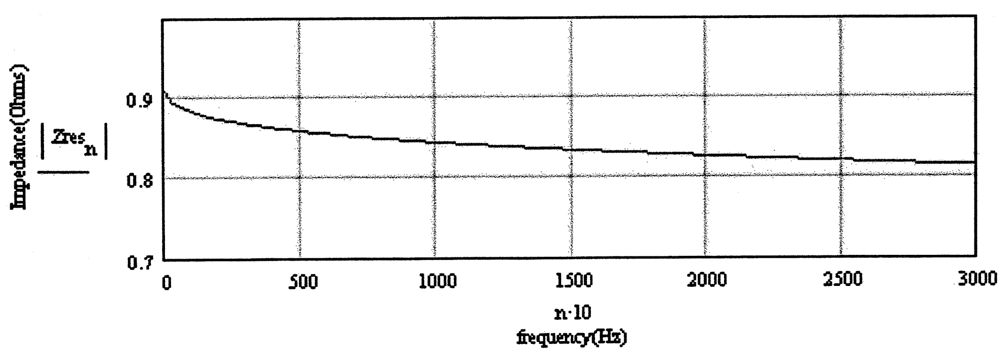
(13)

(14)

$$Zres_n := \frac{Zm2_n}{Zm1_n}$$

Mutual Impeadance for the Interface

In order to compare the measured voltage levels on the probe wire the need to project to a radial of distance of 50 feet. This is accomplished by computing the complex mutual impedance ratio and multiplying it by the probe wire voltage Equation 14 shows the relationship for the impedance labled Zres.



Measured Probe Wire Voltage

The following tables and graphs are created from data aquired by the Tectronics(tm) O-scope. The data was put into tablular format and imported into Mathcad for analysis.

$DCoffset := -0.018$

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table :=

	0	1
0	0	0
1	-0.05	0.044
2	-0.04996	0.0464
3	-0.04992	0.0472
4	-0.04988	0.0504
5	-0.04984	0.0512
6	-0.0498	0.0496
7	-0.04976	0.044
8	-0.04972	0.0408
9	-0.04968	0.0408
10	-0.04964	0.0396

$\text{time} := \text{table}^{\langle 0 \rangle}$

$\text{Volts} := \text{DCoffset} + \left[(10 \cdot \text{table})^{\langle 1 \rangle}\right]$

Time domain data from the "probe wire measurement" was exported from wavestar(tm) and imported into mathcad via the above input table.

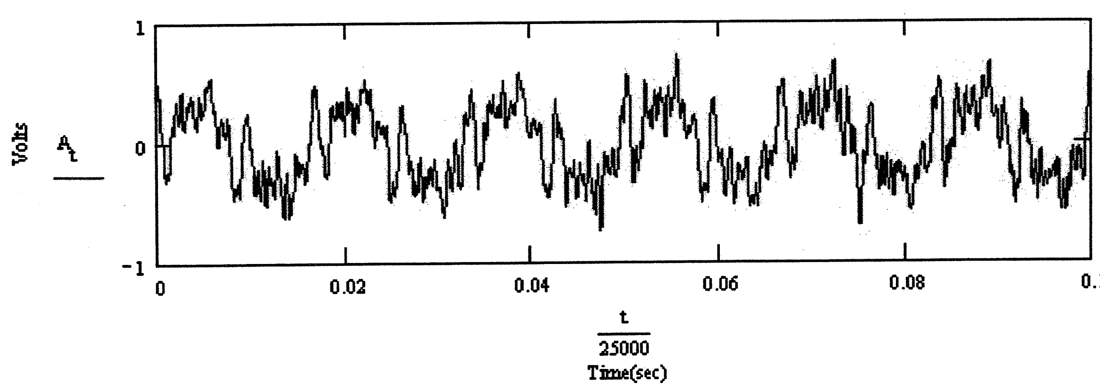
$\frac{1}{0.049960 - 0.049920} = 2.5 \cdot 10^4$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0..2499$

$A_t := \text{Volts}_t$



Take Fourier transform:

$c := \text{CFFT}(\text{Volts})$

$N := \text{last}(c)$

$N := 2499$

Complex frequency vector

$j := -0..N$

$\text{Vres}_j := c_j \cdot \text{Zres}_j$

The voltage in frequency domain is multipled by Zres to determine the interface voltage.

Probe Wire Measurement Frequency Domain(60 to 10kHz)

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Thresholds

From IEEE 776 the harmonic threshold for greater than 3 harmonics in the range of 2 to 17 is given by equation 15 below. From IEEE 776 the harmonic threshhold for greater than 3 harmonics in the range of 18 to 50 is given in equation 16 below. VP is the 60 Hz voltage for the zone 1. Refer to IEEE 776 for definitions. Vdl is the lower order harmonic voltage threshold limit, Vdh is the higher order larmonic voltage threshold limit.

$n1 := 1..102$

n1 is the index factor for calculating the harmonic threshhold below 1020 hz(17th harmonic).

$Vp := 0.333$

$$Vdl_{n1} := Vp \cdot \left(\frac{n1}{6}\right)^{-2.7}$$

(15)

Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 60 Hz and 1000 Hz.

n2 is the index factor for calculating the harmonic threshhold above 1080 hz(18th harmonic) to 3000 hz(50th harmonic).

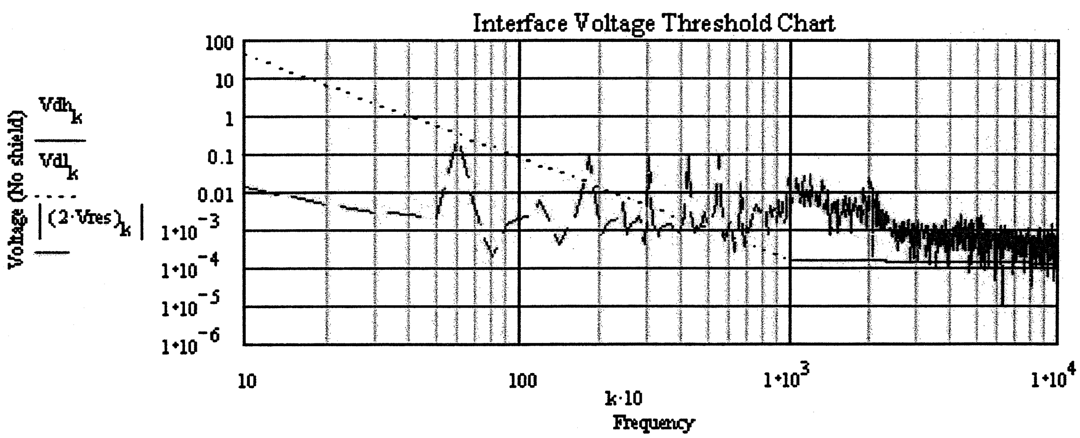
$n2 := 102..2499$

$$Vdh_{n2} := Vp \cdot \frac{1}{17^{2.7} + \left(\frac{n2}{6}\right)^{1.2}}$$

(16)

Where Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 1020 Hz and 3000 Hz. Given below is the voltage threshold chart. The chart compares the projected probe wire voltage levels to the threshold values given in IEEE776.

$k := 1..2499$



The tabulated data given below shows the how much the probe wire threshold voltage is or is not exceeded for a given frequency from the zone 1 values given in IEEE 776. Note these values are normalized to 1kM.

$Vover_{n1} := -Vdl_{n1} + \left|1.2 \cdot Vres_{n1}\right|$

$Vover_{n2} := -Vdh_{n2} + \left|1.2 \cdot Vres_{n2}\right|$

$x := 1..50$

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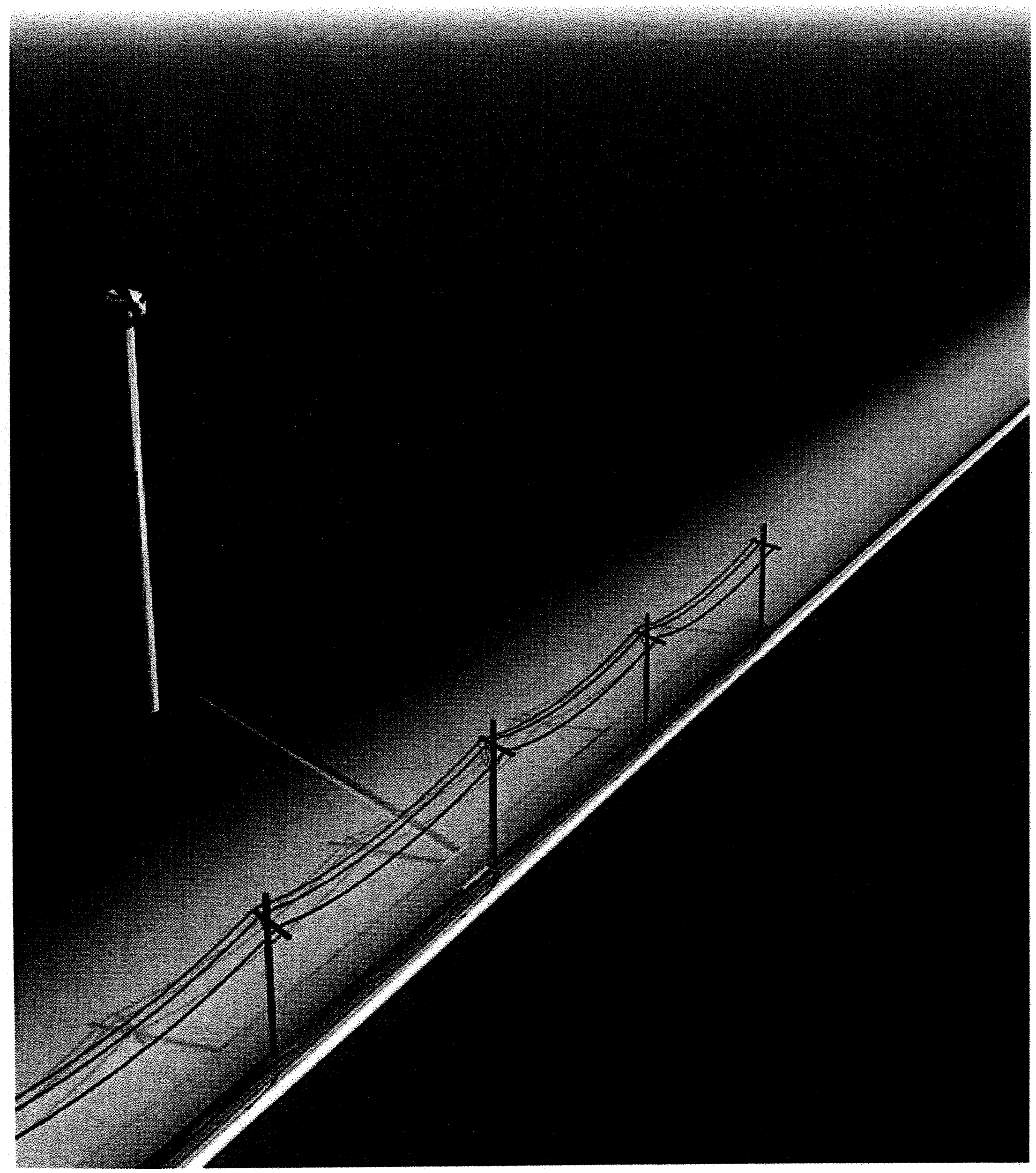
$Vover_{x \cdot 6} =$

-0.05
-0.044
0.083
$-2.205 \cdot 10^{-3}$
0.101
$-9.427 \cdot 10^{-4}$
0.106
$2.13 \cdot 10^{-3}$
0.119
$1.331 \cdot 10^{-3}$
0.02
$2.56 \cdot 10^{-3}$
$2.276 \cdot 10^{-3}$
$4.348 \cdot 10^{-3}$
$3.735 \cdot 10^{-3}$
$2.369 \cdot 10^{-3}$

Testing and Analysis Section 31

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Modified Probe Wire Test, Section 31



Background

Probe wire voltage/current tests along with voice-pair voltage tests were conducted within the Lake Benton area by personell from "Energy Maintence Service" located in Gary, South Dakota at the direction of "Wilkins Consulting" located in Tehachapi, California, for the purpose of determining the cause(s) of the telecommunication interferance experieced by ITC customers. Wilkins Consulting has created this Mathcad(tm) calculation sheet to take the data aquired by EMS and compare it to relevent IEEE standards.

The standard the data is compared to is IEEE776 titled "IEEE Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines." The scope of the standard addresses the inductive environment that exists in the vicinity of electric power and wire-line telecommunication systems and the interfering effect that may be produced. As taken from the standard "Inductive Interferance is defined as an effect, arising from the characteristics and inductive relations of electric supply and telecommunication systems. It is of such character and magnitude that it would prevent the telecommunication circuits from rendering service satisfactorily and economicaly if methods of inductive coordination were not applied". This sheet uses methods givin in this standard to determine the amount of inductive influence the power system has on the telecommunication system.

This sheet uses voltage/current measurements aquired from a modified probe wire test underneath 34.5 kV power lines located near Lake Benton, Minnesota, along with the calculated mutual impeadance between the the overhead conductors and the probe wire to predice the interfering current from the overhead conductors and the induced voltage on Interstate Telecommunication Coorperative's telecommunication lines. This is then compared to the actual voltages measured on the telecommunication line. The methods used to perfrom the calcualtions are based on procedures given by the Institute of Electronic and Electrical Engineers(IEEE) standards 776 and 367. However, some of the test parameters were changed so that the maximum influence over the phone cable could be assesed. For example, a 16 guage wire was used instead of a 22 gauge and the mesurements were made directly over the telecommunication line. Since this is the case the mutual impeadace will be used to project the voltage leves for an interface at a radial distance of 50 feet from the geometric mean of the phase conductors. Once this value is determined it will be compred to the "C message wieghted values" given in IEEE 776 to see if the interferance from the overhead conductors exceed recommended values given.

The instrument used to make such measuremtns is a Tektronics(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1x probe was used to measure the voltage and a standard Tektronix amp clamp probe was used to measure the current. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintance Service. Wilkins Consulting exported the data out of Wavestare to a standard text file. The data was formated in text and laid out in comma seperated values. The data was then imported into a Mathacad work sheet for analysis. This is that sheet.

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Probe Wire Measurement Setup:

As taken from IEEE 776 section 4.2.4 the probe wire measuremnt was accomplished by putting two stakes into the ground directly over the telecommunication line and parallel to both the power and telecommunications lines.(Note: The stakes were placed into the ground 24 in)

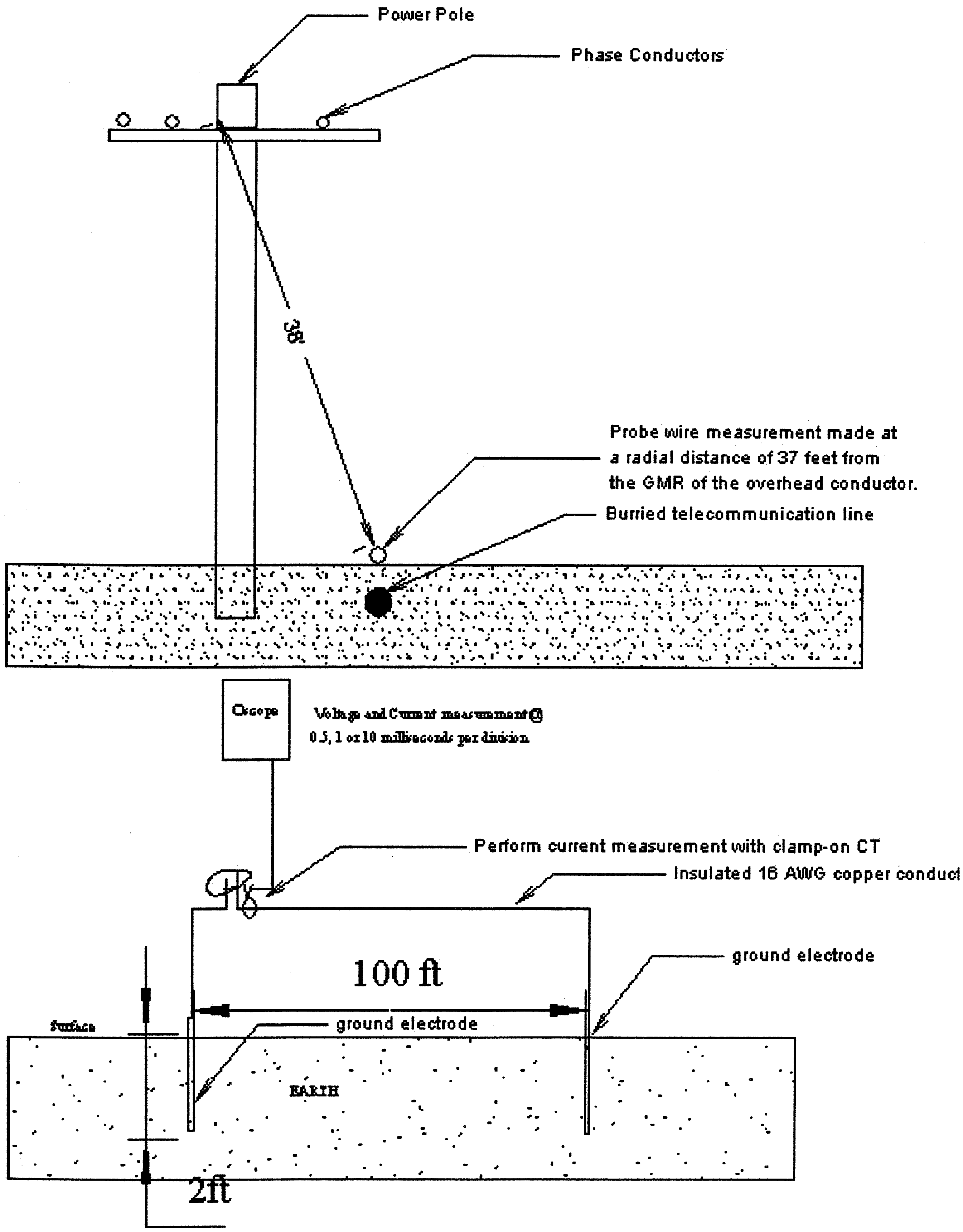

Figure 1A
Figure 1B

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Mutual Impeadance

The mutual Impeadance allows us to project the interfering voltage on the telecommunication line as well as to estime the interfering current on the power lines. The mutual impedance between each conductor is calculated by estimating the soil resistivelty, the geometrical and electromagnetic relationships. In the calculations that follow, the mutual impedance between the disturbing and the disturbed circuits is determined. Since the lines under consideration are parallel, the total exposure is easily determined. The method used to calculate the mutual impeadance will ignore phase change since not of the run pass through transposed sections. Formulation for calculating the external mutual impedance of parallel supply and telecommunication circuits was developed by J. R. Carson Reverence [B9] or IEEE 367. The general configuration for mutual impedance is shown in Figure 2.

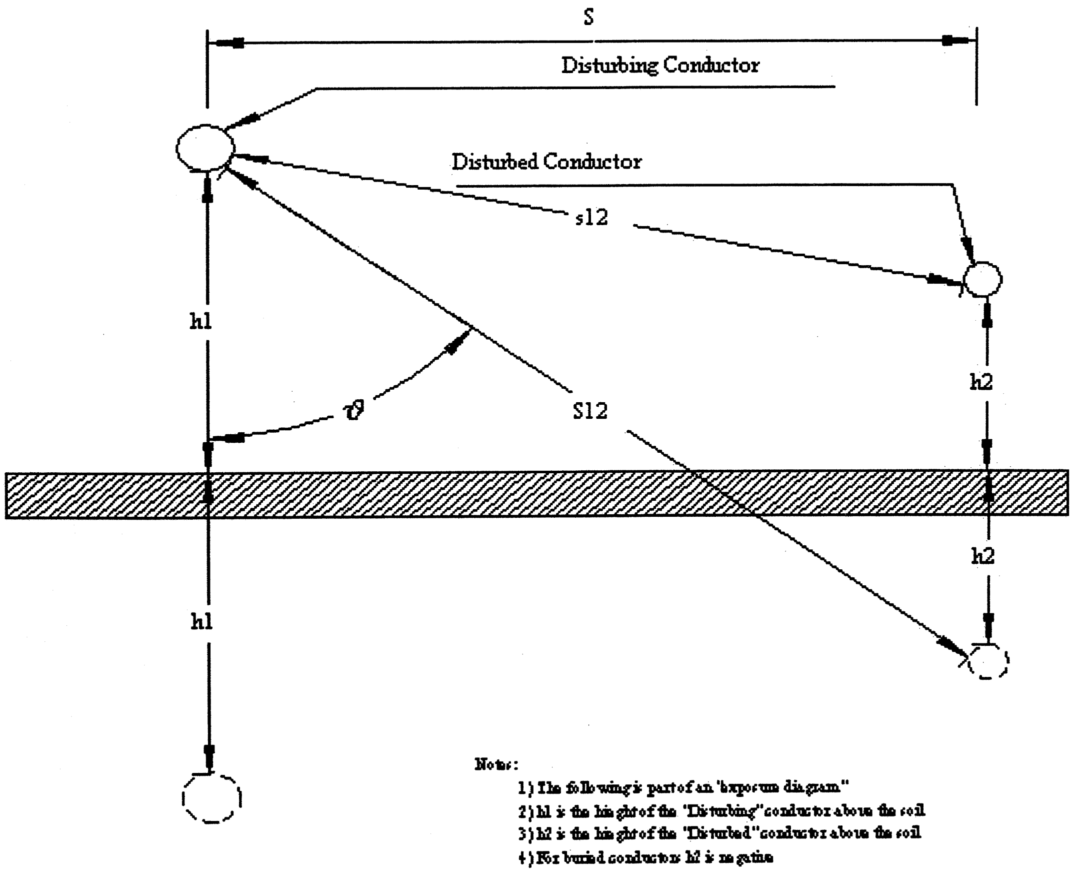

Figure 2

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Shield Factor

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Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. Zm1 is the mutual impedance between the probewire and the imaginary conductor that makes up the interfering current

$$\text{Exposure} := 1$$

(1)

$$n := 1..2500$$

(2)

$$f_n := 10 \cdot n$$

(3)

$$h2 := -0.61$$

(4)

$$h1 := 11$$

(5)

$$S := 1$$

(6)

$$\sigma := \frac{1}{100}$$

(7)

$$\omega_n := 2 \cdot \pi \cdot f_n$$

(8)

$$\gamma_n := \left[(j) \cdot \omega_n \cdot 4 \cdot \pi \cdot 10^{-7} \cdot \sigma\right]^{\frac{1}{2}}$$

(9)

$$D0 := \left[\left(S^2\right) + (h1 - h2)^2\right]^{0.5}$$

(10)

$$D1_n := \left[\left(S^2\right) + \left(h1 + h2 + \frac{2}{\gamma_n}\right)^2\right]^{0.5}$$

(11)

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$$Zm1_n := Exposure \cdot 3 \cdot j \cdot \omega_n \cdot \left(\frac{4\,\pi}{2 \cdot \pi} \cdot 10^{-7}\right) \cdot \left[\ln\left[\frac{(D1_n)}{D0}\right] - \frac{1}{12} \cdot \left(\frac{2}{\gamma_n \cdot D1_n}\right)^4\right]$$

(12)

$$\theta1_n := \left(\frac{180}{\pi}\right) \cdot atan\left(\left(\frac{Im(Zm1_n)}{Re(Zm1_n)}\right)\right)$$

(13)

Where:

Equation 1 is the parallel exposure in the section under question
Equation 2 is the the harmonic number
Equation 3 is the coorsponding frequency of the nth harmonic
Equation 4 is the depth of the buried cable is meters
Equation 5 is the hieght of the power line
Equation 6 is the geometric mean horizontal separation of the conductors
Equation 7 is the conductivety of the soil
Equation 8 is the radian frequency of the nth harmonic
Equation 9 is the related to the complex progation constant
Equation 10 D0 is the distance between the two conductors
Equation 11 D1 is the distance between the offending conductor and the image of the disturbed conductor.
Equation 12 Zm is the Mutual Impedance. Note: The 3 multiplier is there for the three phase conductors.
Equation 13 $\theta(n)$ is the angle of the mutual impeadance

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. ZM2 is the mutual impedance betwwen the imaginary conductor that carries the interfering current and the interface.

$Exposure := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$hI2 := 0$

(4)

$hI1 := 10$

(5)

$SI := 16$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2 \cdot \pi \cdot f_n$

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(8)

$$\gamma_n := \left[(j)\cdot\omega_n\cdot 4\cdot\pi\cdot 10^{-7}\cdot\sigma\right]^{\frac{1}{2}}$$

(9)

$$DI0 := \left[\left(SI^2\right) + (hI1 - hI2)^2\right]^{0.5}$$

(10)

$$DI1_n := \left[\left(SI^2\right) + \left(hI1 + hI2 + \frac{2}{\gamma_n}\right)^2\right]^{0.5}$$

(11)

$$Zm2_n := Exposure\cdot 3\cdot j\cdot\omega_n\cdot\left(\frac{4\,\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{\left(DI1_n\right)}{DI0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n\cdot DI1_n}\right)^4\right]$$

(12)

$$\theta 2_n := \left(\frac{180}{\pi}\right)\cdot\operatorname{atan}\left(\left(\frac{\operatorname{Im}\left(Zm2_n\right)}{\operatorname{Re}\left(Zm2_n\right)}\right)\right)$$

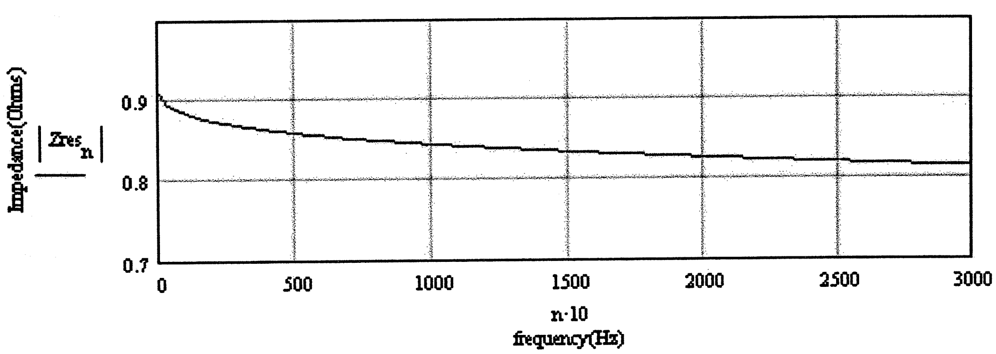
(13)

(14)

$$Zres_n := \frac{Zm2_n}{Zm1_n}$$

Mutual Impeadance for the Interface

In order to compare the measured voltage levels on the probe wire the need to project to a radial of distance of 50 feet. This is accomplished by computing the complex mutual impedance ratio and multiplying it by the probe wire voltage Equation 14 shows the relationship for the impedance labled Zres.



Measured Probe Wire Voltage

The following tables and graphs are created from data aquired by the Tectronics(tm) O-scope. The data was put into tablular format and imported into Mathcad for analysis.

DCoffset := -0.018

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table :=

	0	1
0	0	0
1	-0.05	0.344
2	-0.04996	0.12
3	-0.04992	0.072
4	-0.04988	0.232
5	-0.04984	-0.024
6	-0.0498	0.056
7	-0.04976	0.056
8	-0.04972	-0.104
9	-0.04968	0.064
10	[illegible]	[illegible]

$time := table^{\langle 0 \rangle}$

$Volts := DCoffset + \left[(1 \cdot table)^{\langle 1 \rangle} \right]$

Time domain data from the "probe wire measurement" was exported from wavestar(tm) and imported into mathcad via the above input table.

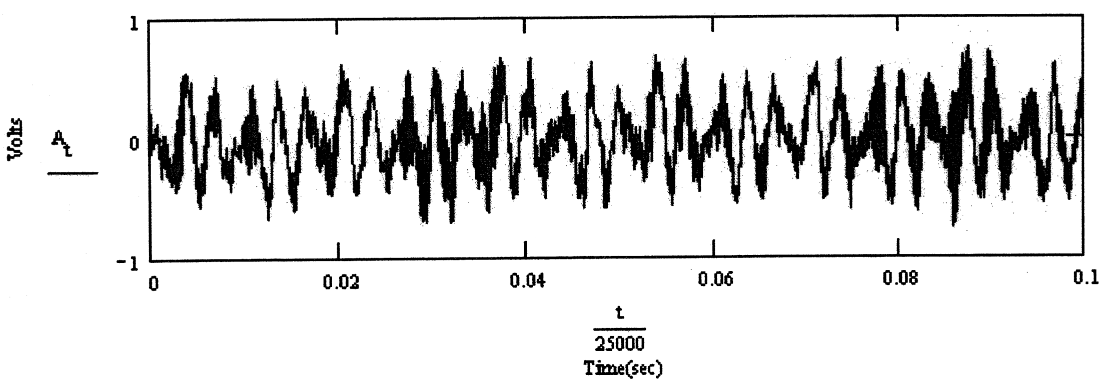
$$\frac{1}{0.049960 - 0.049920} = 2.5 \cdot 10^4$$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0..2499$

$A_t := Volts_t$



Take Fourier transform:

$c := CFFT(Volts)$

$N := last(c)$

$N := 2499$

Complex frequency vector

$j := -0..N$

$Vres_j := c_j \cdot Zres_j$

The voltage in frequency domain is multipled by Zres to determine the interface voltage.

Probe Wire Measurement Frequency Domain(60 to 10kHz)

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Thresholds

From IEEE 776 the harmonic threshold for greater than 3 harmonics in the range of 2 to 17 is given by equation 15 below. From IEEE 776 the harmonic threshhold for greater than 3 harmonics in the range of 18 to 50 is given in equation 16 below. VP is the 60 Hz voltage for the zone 1. Refer to IEEE 776 for definitions. Vdl is the lower order harmonic voltage threshold limit, Vdh is the higher order larmonic voltage threshold limit.

$n1 := 1 .. 102$

n1 is the index factor for calculating the harmonic threshhold below 1020 hz(17th harmonic).

$Vp := 0.333$

$$Vdl_{n1} := Vp \cdot \left(\frac{n1}{6}\right)^{-2.7}$$

(15)

Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 60 Hz and 1000 Hz.

n2 is the index factor for calculating the harmonic threshhold above 1080 hz(18th harmonic) to 3000 hz(50th harmonic).

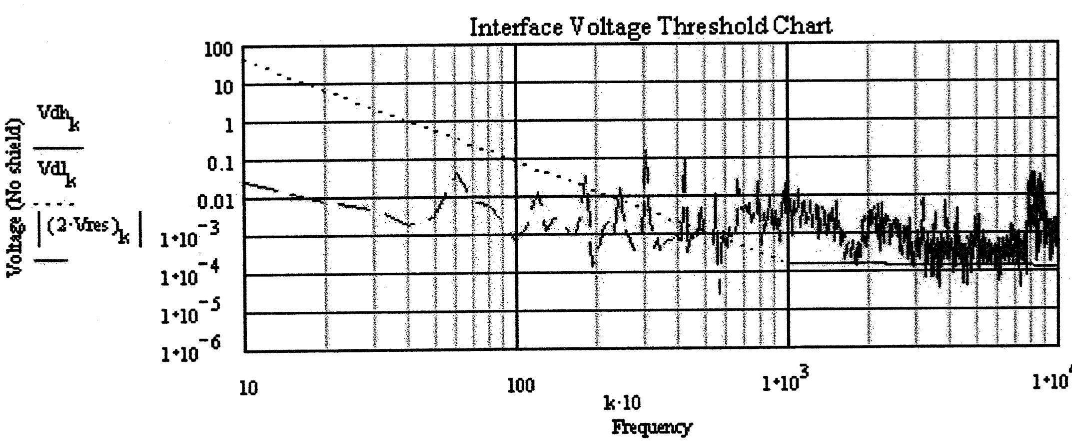
$n2 := 102 .. 2499$

$$Vdh_{n2} := Vp \cdot \frac{1}{17^{2.7} + \left(\frac{n2}{6}\right)^{1.2}}$$

(16)

Where Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 1020 Hz and 3000 Hz. Given below is the voltage threshold chart. The chart compares the projected probe wire voltage levels to the threshold values given in IEEE776.

$k := 1 .. 2499$



The tabulated data given below shows the how much the probe wire threshold voltage is or is not exceeded for a given frequency from the zone 1 values given in IEEE 776. Note these values are normalized to 1kM.

$Vover_{n1} := -Vdl_{n1} + \left| 1.2 \cdot Vres_{n1} \right|$

$Vover_{n2} := -Vdh_{n2} + \left| 1.2 \cdot Vres_{n2} \right|$

$x := 1 .. 50$

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$Vover_{x \cdot 6} =$

-0.287
-0.037
0.021
0.011
0.231
$-1.958 \cdot 10^{-3}$
0.149
$6.808 \cdot 10^{-3}$
0.012
$-2.94 \cdot 10^{-4}$
0.028
$8.204 \cdot 10^{-3}$
0.03
$3.119 \cdot 10^{-3}$
$4.007 \cdot 10^{-3}$
0.019

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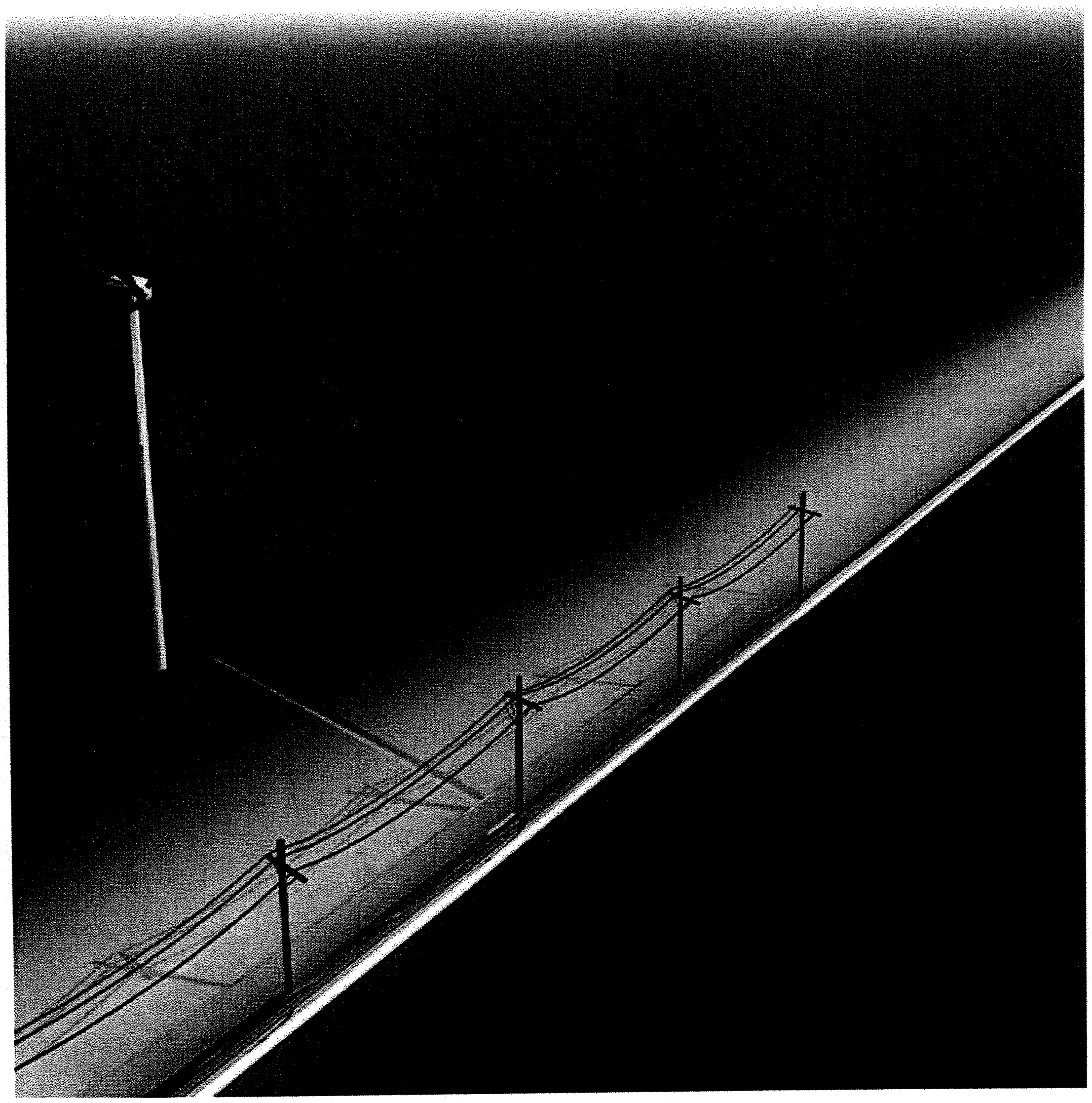
Testing and Analysis Section 34

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Modified Probe Wire Test, Section 34



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The instrument used to make such measuremtns is a Tektronics(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1x probe was used to measure the voltage and a standard Tektronix amp clamp probe was used to measure the current. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintance Service. Wilkins Consulting exported the data out of Wavestare to a standard text file. The data was formated in text and laid out in comma seperated values. The data was then imported into a Mathacad work sheet for analysis. This is that sheet.

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Probe Wire Measurement Setup:

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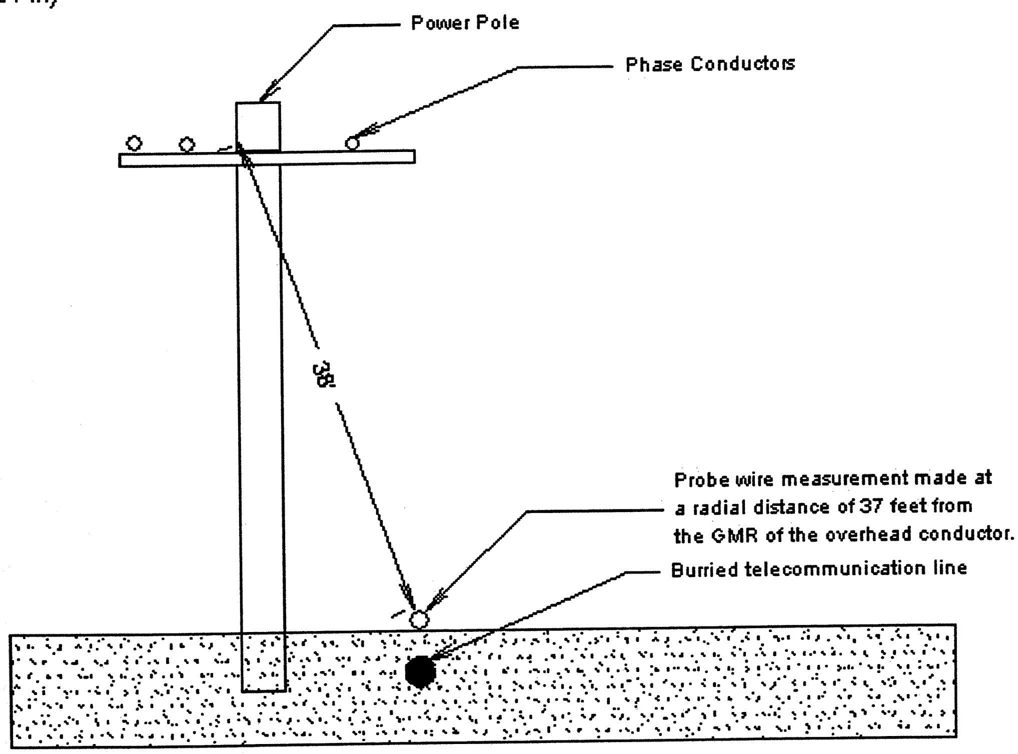

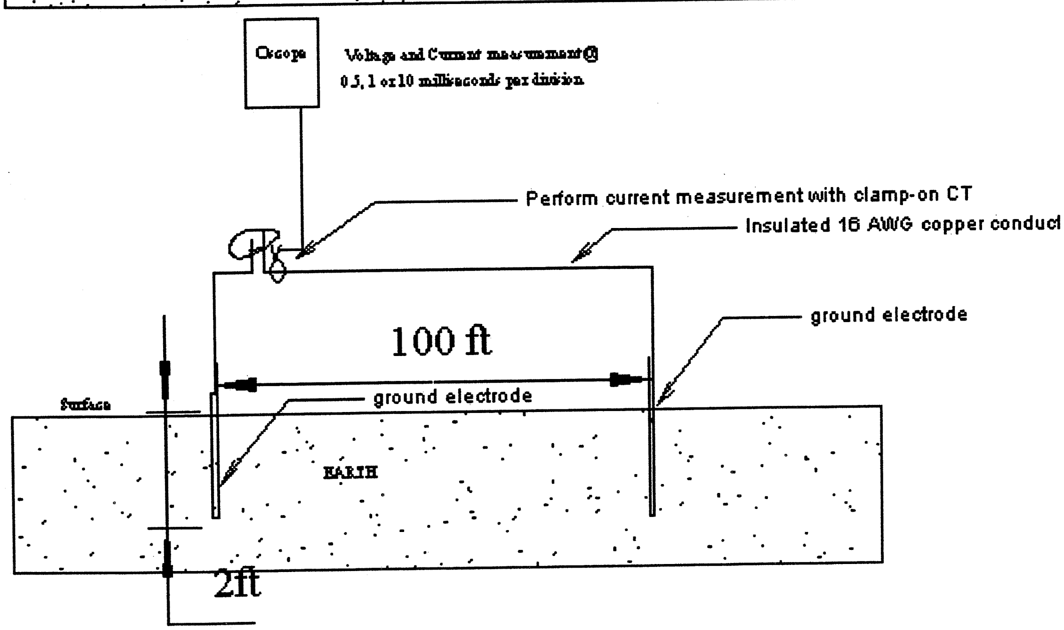

Figure 1A
Figure 1B

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Mutual Impeadance

The mutual Impeadance allows us to project the interfering voltage on the telecommunication line as well as to estime the interfering current on the power lines. The mutual impedance between each conductor is calculated by estimating the soil resistivelty, the geometrical and electromagnetic relationships. In the calculations that follow, the mutual impedance between the disturbing and the disturbed circuits is determined. Since the lines under consideration are parallel, the total exposure is easily determined. The method used to calculate the mutual impeadance will ignore phase change since not of the run pass through transposed sections. Formulation for calculating the external mutual impedance of parallel supply and telecommunication circuits was developed by J. R. Carson Reverence [B9] or IEEE 367. The general configuration for mutual impedance is shown in Figure 2.

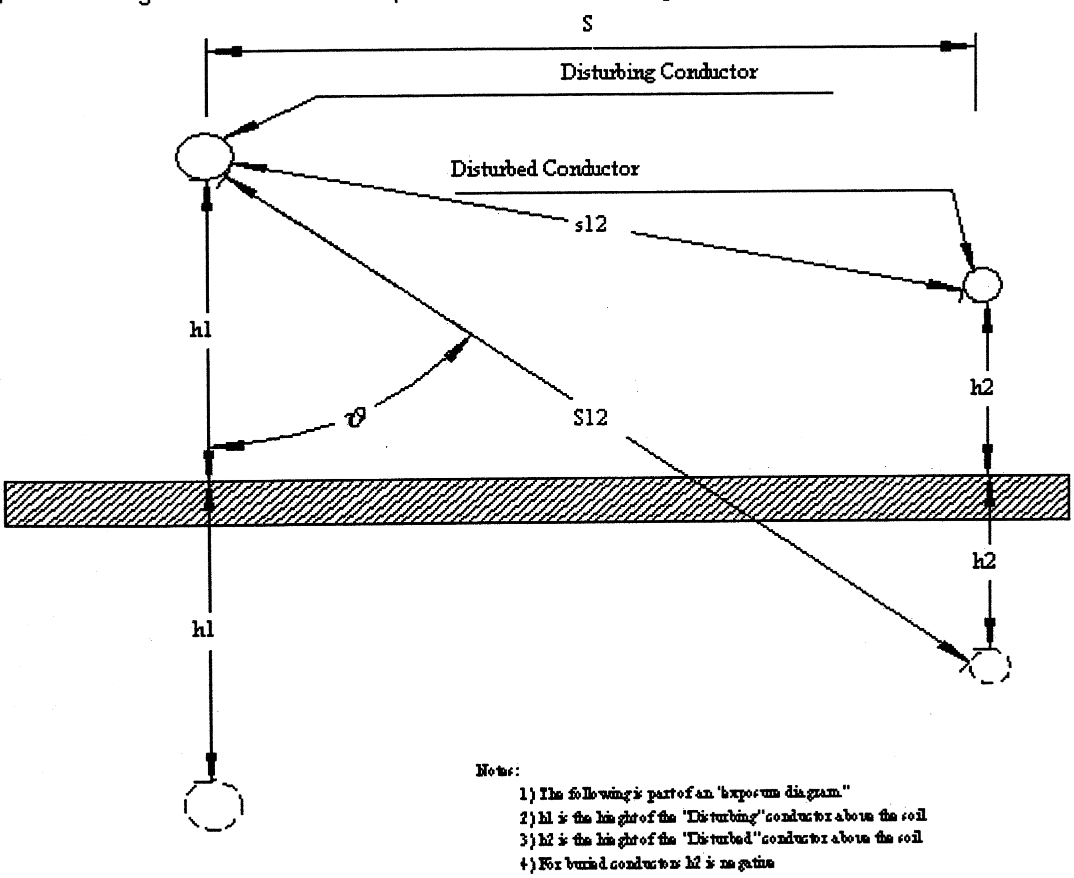

Figure 2

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Shield Factor

The electromagnetically induced voltage measured by the probe wire is the voltage induced in an unshielded telecommunication line. A shield factor is used to take into account the shielding action of all grounded conductors (overhead ground wires, rails, metallic pipes), including metallic sheaths of telecommunication cables, etc., in an inductive exposure. The shield factor used for this study is a combination of the overhead ground wire and the aluminum tape that surrounds the telecommunication cable conductors. Taken from tables 6 and 7 in IEEE 367 the shield factor used is 1. The shield factor is not included so that worst case values can be shown. However a coorective shield factor for each section will be given.

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. Zm1 is the mutual impedance between the probewire and the imaginary conductor that makes up the interfering current

$\text{Exposure} := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$h2 := -0.61$

(4)

$h1 := 11$

(5)

$S := 1$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2 \cdot \pi \cdot f_n$

(8)

$\gamma_n := \left[(j) \cdot \omega_n \cdot 4 \cdot \pi \cdot 10^{-7} \cdot \sigma \right]^{\frac{1}{2}}$

(9)

$D0 := \left[\left(S^2\right) + (h1 - h2)^2 \right]^{0.5}$

(10)

$D1_n := \left[\left(S^2\right) + \left(h1 + h2 + \frac{2}{\gamma_n}\right)^2 \right]^{0.5}$

(11)

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$$Zm1_n := Exposure \cdot 3 \cdot j \cdot \omega_n \cdot \left(\frac{4\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{(D1_n)}{D0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n \cdot D1_n}\right)^4\right]$$

(12)

$$\theta 1_n := \left(\frac{180}{\pi}\right) atan\left(\left(\frac{Im(Zm1_n)}{Re(Zm1_n)}\right)\right)$$

(13)

Where:

Equation 1 is the parallel exposure in the section under question
Equation 2 is the the harmonic number
Equation 3 is the coorsponding frequency of the nth harmonic
Equation 4 is the depth of the buried cable is meters
Equation 5 is the hieght of the power line
Equation 6 is the geometric mean horizontal separation of the conductors
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Equation 10 D0 is the distance between the two conductors
Equation 11 D1 is the distance between the offending conductor and the image of the disturbed conductor.
Equation 12 Zm is the Mutual Impedance. Note: The 3 multiplier is there for the three phase conductors.
Equation 13 θ(n) is the angle of the mutual impeadance

Calculations

The following formulas were used to derive the mutual impeadance between the Power Lines and the Telecommunication lines to determine the inductive exposure with uniform separation between a supply line and a telecommunication line. Figure 2 illustrates the geometrical relationship. ZM2 is the mutual impedance betwwen the imaginary conductor that carries the interfering current and the interface.

$Exposure := 1$

(1)

$n := 1 .. 2500$

(2)

$f_n := 10 \cdot n$

(3)

$hI2 := 0$

(4)

$hI1 := 10$

(5)

$SI := 16$

(6)

$\sigma := \frac{1}{100}$

(7)

$\omega_n := 2\cdot\pi\cdot f_n$

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(8)

$$\gamma_n := \left[(j)\cdot\omega_n\cdot 4\cdot\pi\cdot 10^{-7}\cdot\sigma\right]^{\frac{1}{2}}$$

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$$DI0 := \left[\left(SI^2\right) + (hI1 - hI2)^2\right]^{0.5}$$

(10)

$$DI1_n := \left[\left(SI^2\right) + \left(hI1 + hI2 + \frac{2}{\gamma_n}\right)^2\right]^{0.5}$$

(11)

$$Zm2_n := Exposure\cdot 3\cdot j\cdot\omega_n\cdot\left(\frac{4\,\pi}{2\cdot\pi}\cdot 10^{-7}\right)\cdot\left[\ln\left[\frac{\left(DI1_n\right)}{DI0}\right] - \frac{1}{12}\cdot\left(\frac{2}{\gamma_n\cdot DI1_n}\right)^4\right]$$

(12)

$$\theta 2_n := \left(\frac{180}{\pi}\right)\,\mathrm{atan}\left(\left(\frac{\mathrm{Im}\left(Zm2_n\right)}{\mathrm{Re}\left(Zm2_n\right)}\right)\right)$$

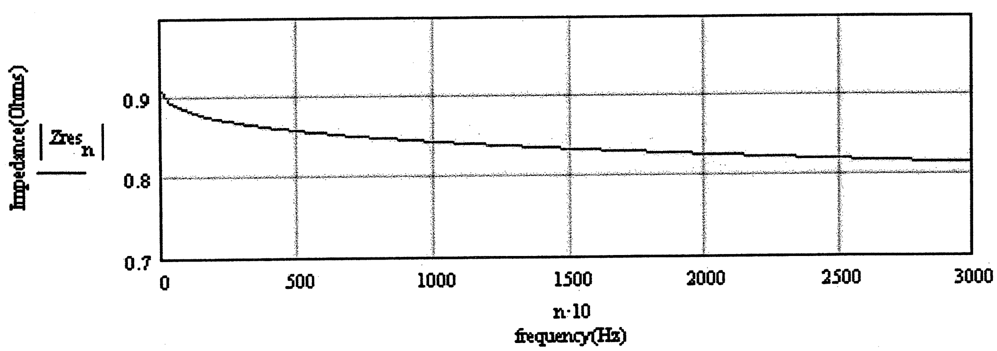
(13)

(14)

$$Zres_n := \frac{Zm2_n}{Zm1_n}$$

Mutual Impeadance for the Interface

In order to compare the measured voltage levels on the probe wire the need to project to a radial of distance of 50 feet. This is accomplished by computing the complex mutual impedance ratio and multiplying it by the probe wire voltage Equation 14 shows the relationship for the impedance labled Zres.



Measured Probe Wire Voltage

The following tables and graphs are created from data aquired by the Tectronics(tm) O-scope. The data was put into tablular format and imported into Mathcad for analysis.

$DCoffset := -0.018$

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table :=

	0	1
0	0	0
1	-0.05	-0.01
2	-0.04996	-0.054
3	-0.04992	0.084
4	-0.04988	0.004
5	-0.04984	0.012
6	-0.0498	0.036
7	-0.04976	0.066
8	-0.04972	0.028
9	-0.04968	0.028
10	[illegible]	[illegible]

$time := table^{\langle 0 \rangle}$

$Volts := DCoffset + \left[(1 \cdot table)^{\langle 1 \rangle} \right]$

Time domain data from the "probe wire measurement" was exported from wavestar(tm) and imported into mathcad via the above input table.

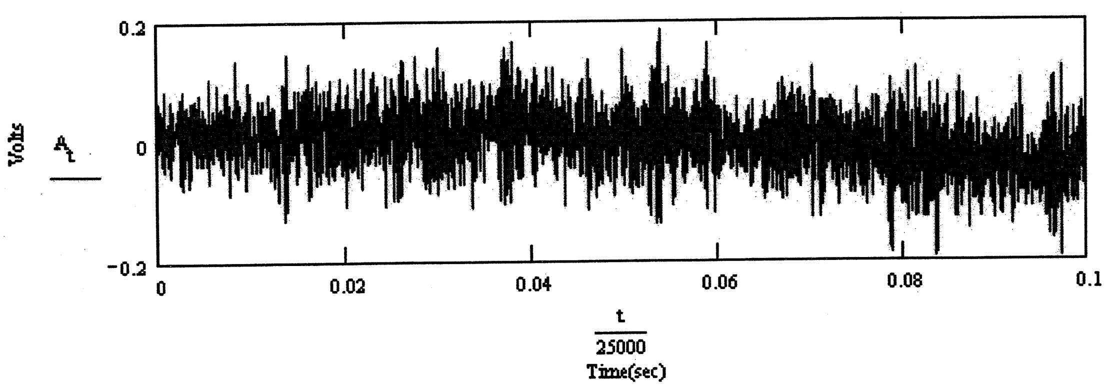
$$\frac{1}{0.049960 - 0.049920} = 2.5 \cdot 10^4$$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0 .. 2499$

$A_t := Volts_t$



Take Fourier transform:

$c := CFFT(Volts)$

$N := last(c)$

$N := 2499$

Complex frequency vector

$j := -0 .. N$

$Vres_j := c_j \cdot Zres_j$

The voltage in frequency domain is multipled by Zres to determine the interface voltage.

Probe Wire Measurement Frequency Domain(60 to 10kHz)

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Thresholds

From IEEE 776 the harmonic threshold for greater than 3 harmonics in the range of 2 to 17 is given by equation 15 below. From IEEE 776 the harmonic threshhold for greater than 3 harmonics in the range of 18 to 50 is given in equation 16 below. VP is the 60 Hz voltage for the zone 1. Refer to IEEE 776 for definitions. Vdl is the lower order harmonic voltage threshold limit, Vdh is the higher order larmonic voltage threshold limit.

$n1 := 1 .. 102$

n1 is the index factor for calculating the harmonic threshhold below 1020 hz(17th harmonic).

$Vp := 0.333$

$$Vdl_{n1} := Vp \cdot \left(\frac{n1}{6}\right)^{-2.7}$$

(15)

Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 60 Hz and 1000 Hz.

n2 is the index factor for calculating the harmonic threshhold above 1080 hz(18th harmonic) to 3000 hz(50th harmonic).

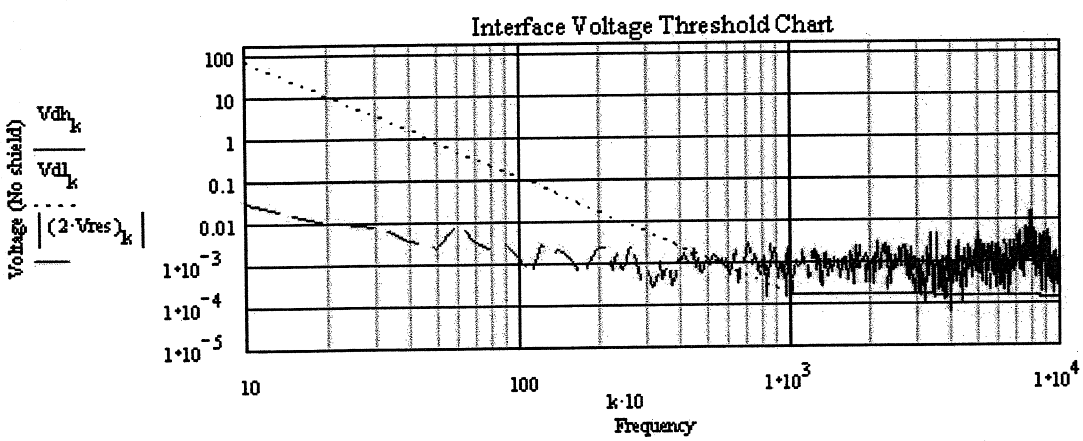
$n2 := 102 .. 2499$

$$Vdh_{n2} := Vp \cdot \frac{1}{17^{2.7} + \left(\frac{n2}{6}\right)^{1.2}}$$

(16)

Where Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 1020 Hz and 3000 Hz. Given below is the voltage threshold chart. The chart compares the projected probe wire voltage levels to the threshold values given in IEEE776.

$k := 1 .. 2499$



The tabulated data given below shows the how much the probe wire threshold voltage is or is not exceeded for a given frequency from the zone 1 values given in IEEE 776. Note these values are normalized to 1kM.

$Vover_{n1} := -Vdl_{n1} + \left| 1.2 \cdot Vres_{n1} \right|$

$Vover_{n2} := -Vdh_{n2} + \left| 1.2 \cdot Vres_{n2} \right|$

$x := 1 .. 50$

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$Vover_{x \cdot 6} =$

-0.325
-0.048
-0.016
$-7.328 \cdot 10^{-3}$
$-3.6 \cdot 10^{-3}$
$-1.76 \cdot 10^{-3}$
$-9.747 \cdot 10^{-4}$
$-7.415 \cdot 10^{-4}$
$1.405 \cdot 10^{-4}$
$-3.23 \cdot 10^{-4}$
$4.645 \cdot 10^{-4}$
$2.988 \cdot 10^{-4}$
$3.183 \cdot 10^{-4}$
$2.302 \cdot 10^{-3}$
$1.04 \cdot 10^{-3}$
$1.315 \cdot 10^{-3}$

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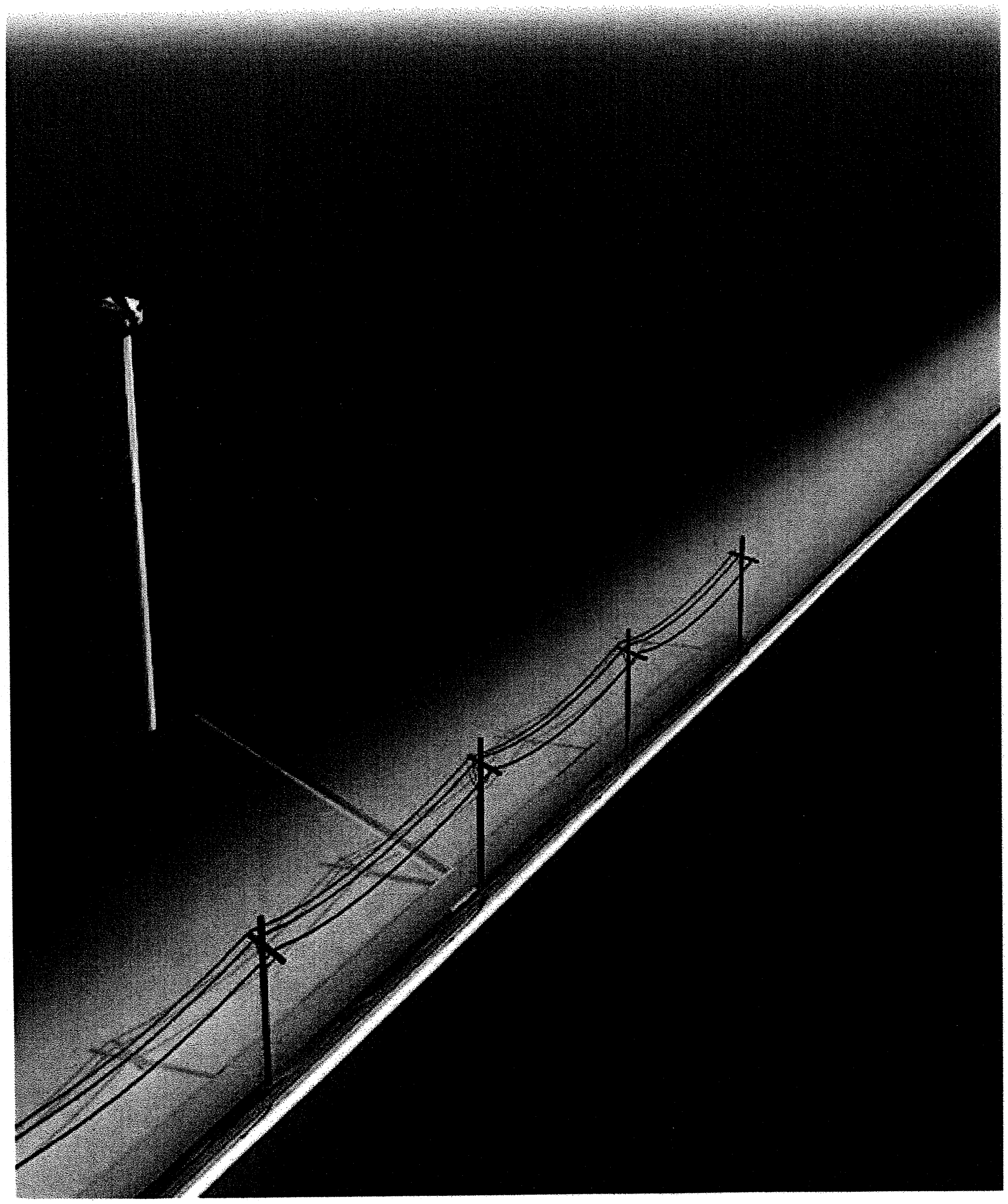
Testing and Analysis Section 35

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Modified Probe Wire Test, Section 35



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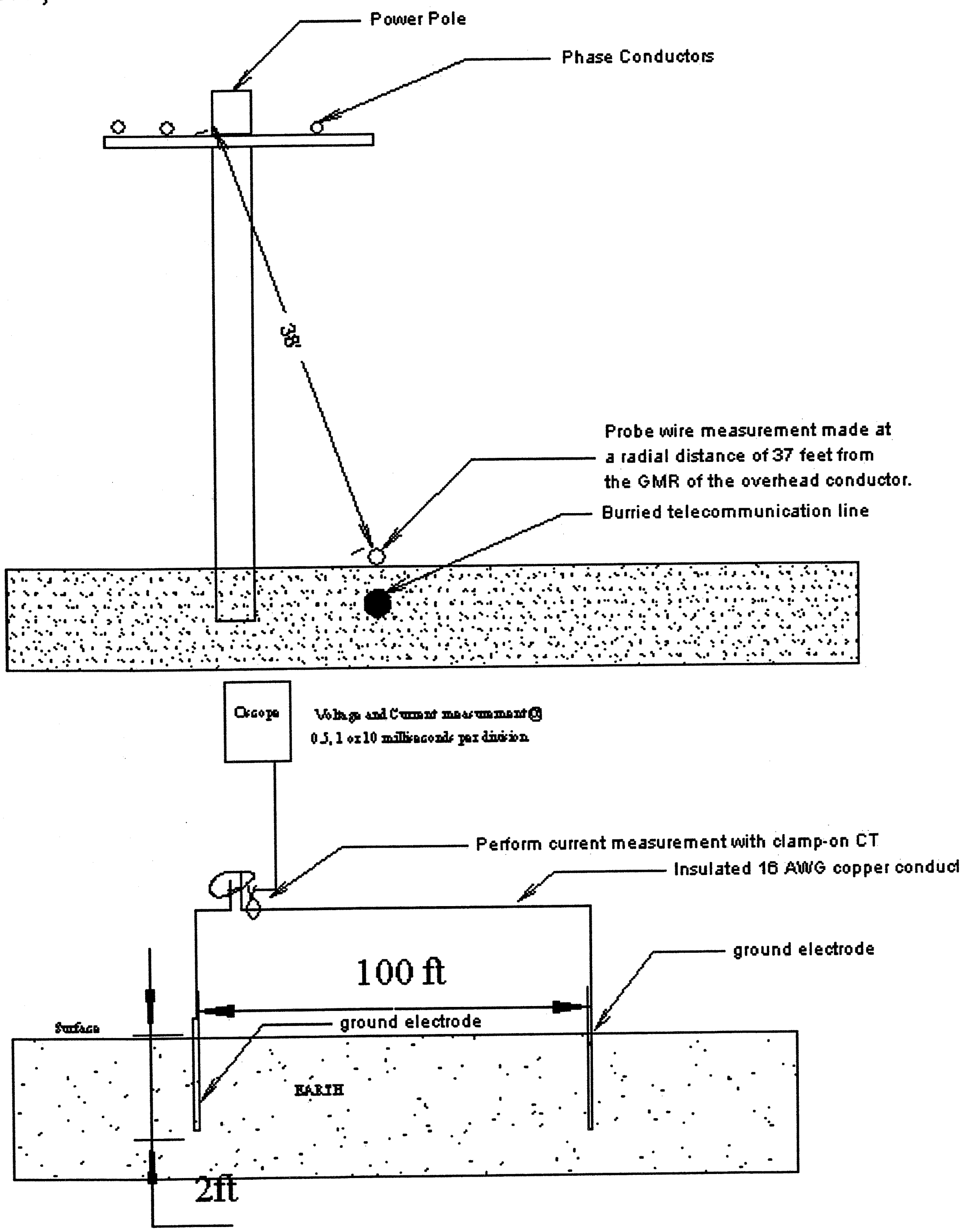

Figure 1A
Figure 1B

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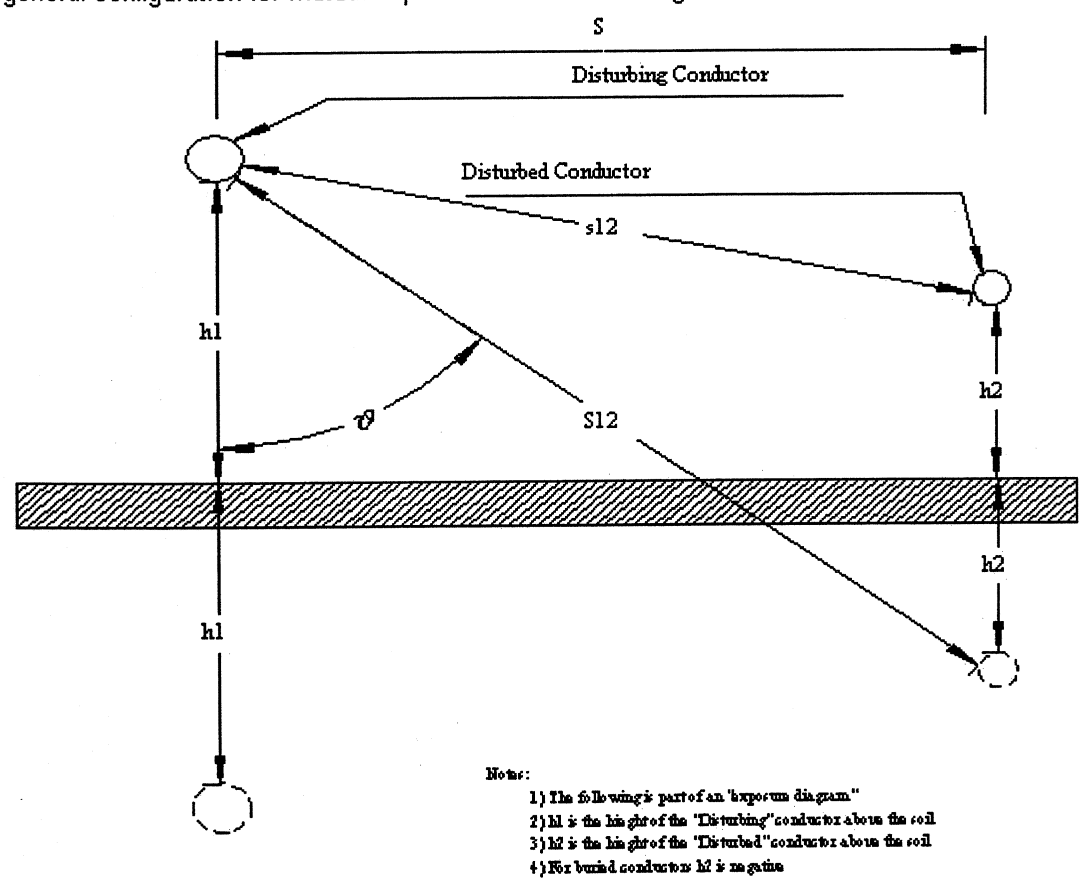

Figure 2

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(12)

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Where: Equation 1 is the parallel exposure in the section under question
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(11)

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(13)

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$$Zres_n := \frac{Zm2_n}{Zm1_n}$$

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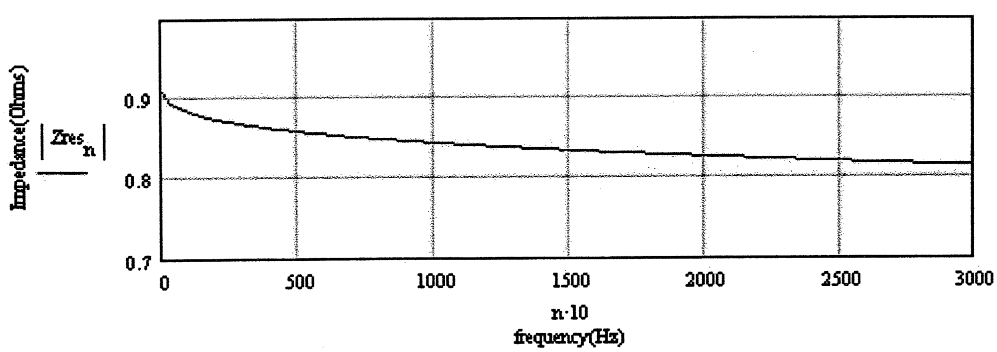

Measured Probe Wire Voltage

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table :=

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3	-0.04992	0.448
4	-0.04988	0.392
5	-0.04984	0.368
6	-0.0498	0.368
7	-0.04976	0.416
8	-0.04972	0.4
9	-0.04968	0.384

$\mathrm{time} := \mathrm{table}^{\langle 0 \rangle}$

$\mathrm{Volts} := \mathrm{DCoffset} + \left[(1 \cdot \mathrm{table})^{\langle 1 \rangle}\right]$

Time domain data from the "probe wire measurement" was exported from wavestar(tm) and imported into mathcad via the above input table.

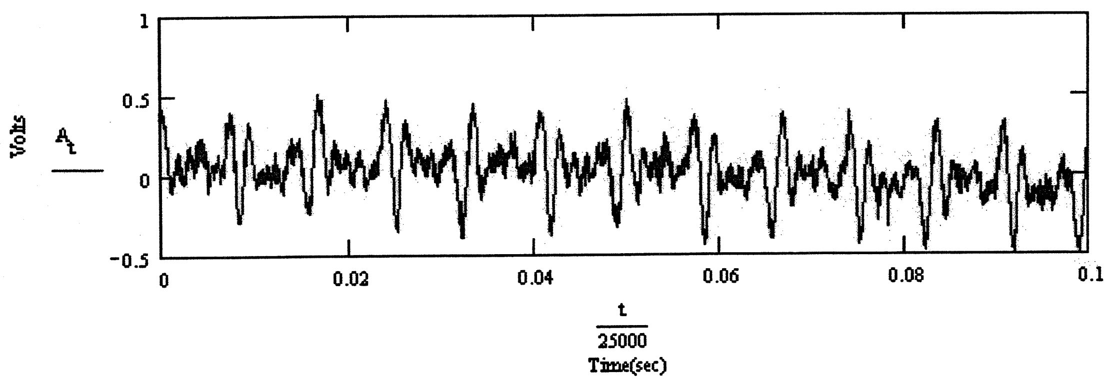
$$\frac{1}{0.049960 - 0.049920} = 2.5 \cdot 10^{4}$$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0 .. 2499$

$A_t := \mathrm{Volts}_t$



Take Fourier transform:

$c := \mathrm{CFFT}(\mathrm{Volts})$

$N := \mathrm{last}(c)$

$N := 2499$

Complex frequency vector

$j := -0 .. N$

$\mathrm{Vres}_j := c_j \cdot \mathrm{Zres}_j$

The voltage in frequency domain is multipled by Zres to determine the interface voltage.

Probe Wire Measurement Frequency Domain(60 to 10kHz)

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Thresholds

From IEEE 776 the harmonic threshold for greater than 3 harmonics in the range of 2 to 17 is given by equation 15 below. From IEEE 776 the harmonic threshhold for greater than 3 harmonics in the range of 18 to 50 is given in equation 16 below. VP is the 60 Hz voltage for the zone 1. Refer to IEEE 776 for definitions. Vdl is the lower order harmonic voltage threshold limit, Vdh is the higher order larmonic voltage threshold limit.

$n1 := 1..102$

n1 is the index factor for calculating the harmonic threshhold below 1020 hz(17th harmonic).

$Vp := 0.333$

$$Vdl_{n1} := Vp \cdot \left(\frac{n1}{6}\right)^{-2.7}$$

(15)

Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 60 Hz and 1000 Hz.

n2 is the index factor for calculating the harmonic threshhold above 1080 hz(18th harmonic) to 3000 hz(50th harmonic).

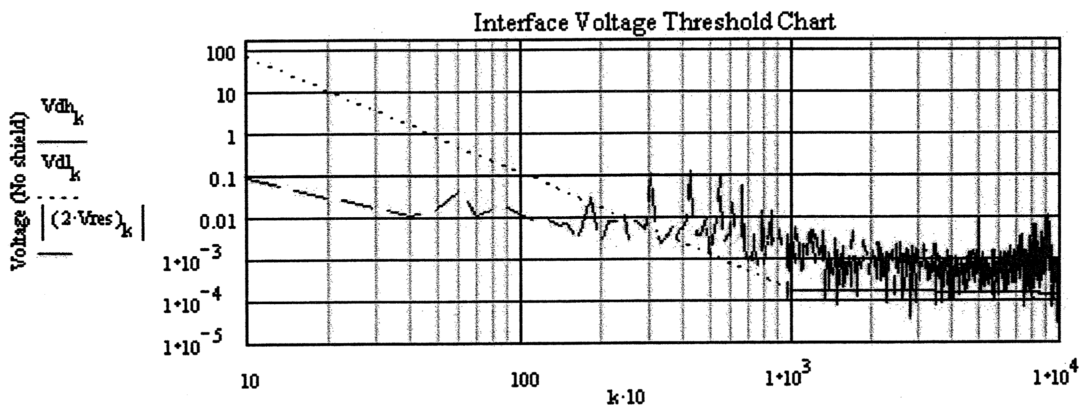
$n2 := 102..2499$

$$Vdh_{n2} := Vp \cdot \frac{1}{17^{2.7} + \left(\frac{n2}{6}\right)^{1.2}}$$

(16)

Where Vd is the distortion limit derived from the measured voltage at 60 hz on the probe wire between 1020 Hz and 3000 Hz. Given below is the voltage threshold chart. The chart compares the projected probe wire voltage levels to the threshold values given in IEEE776.

$k := 1..2499$



The tabulated data given below shows the how much the probe wire threshold voltage is or is not exceeded for a given frequency from the zone 1 values given in IEEE 776. Note these values are normalized to 1kM.

$Vover_{n1} := -Vdl_{n1} + \left| 1.2 \cdot Vres_{n1} \right|$

$Vover_{n2} := -Vdh_{n2} + \left| 1.2 \cdot Vres_{n2} \right|$

$x := 1..50$

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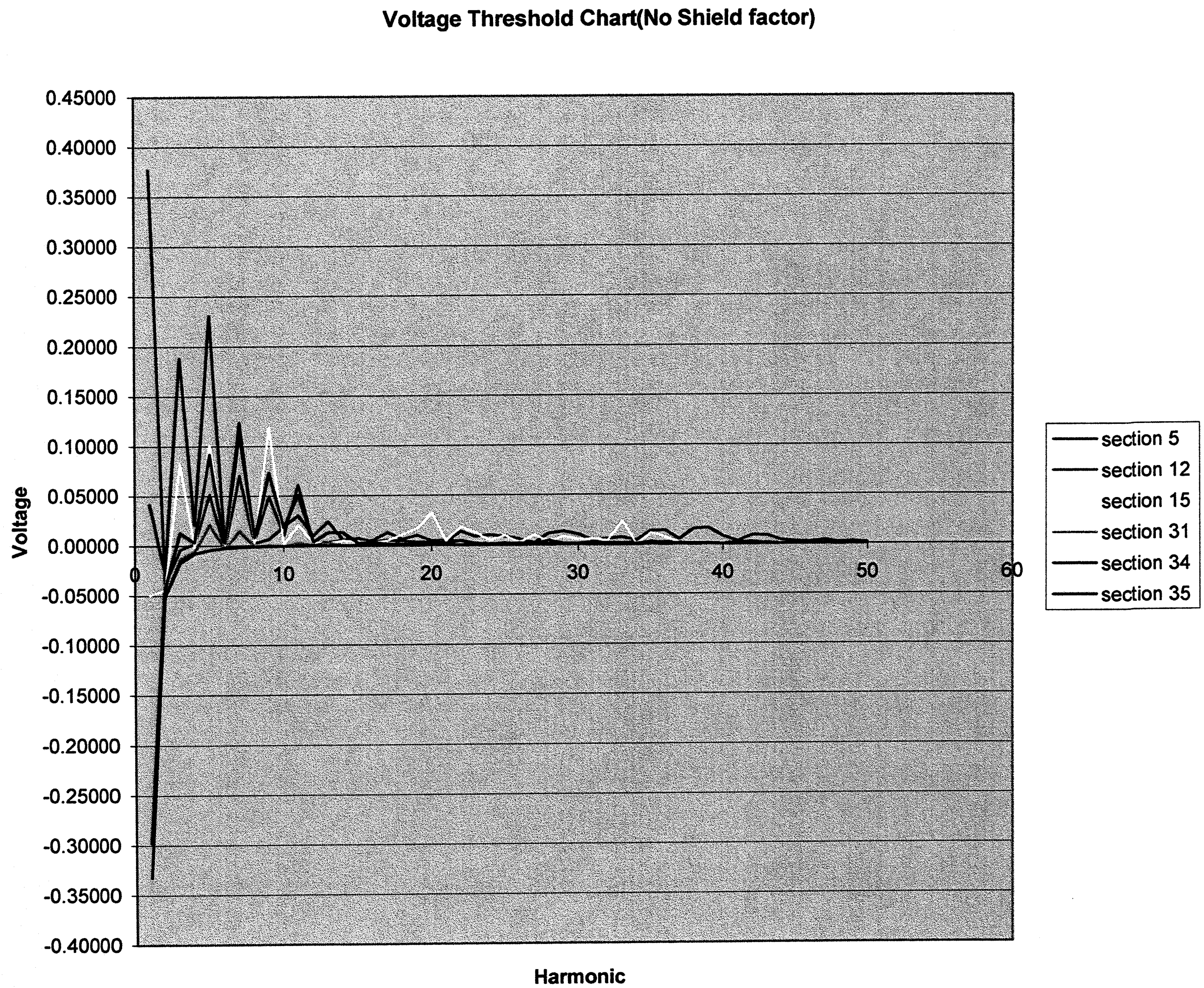
$Vover_{x \cdot 6} =$

-0.298
-0.043
0.013
$2.931 \cdot 10^{-3}$
0.091
$2.538 \cdot 10^{-3}$
0.11
$7.74 \cdot 10^{-3}$
0.073
0.018
0.05
$2.883 \cdot 10^{-3}$
0.013
0.013
$2.157 \cdot 10^{-3}$
$3.019 \cdot 10^{-3}$

Voltage Threshold Chart



Above is the voltage threshold chart. Positive values indicate that the recommended probe wires field levels are exceeded. As the reader can see the values are exceeded in each section. However, as one can see, even the lower order harmonics are exceeded. This suggests that even the squirrel cage machines can negatively impact customer service on the local telecommunication systems. Note: These test results do not take into account the floor noise on the scope. However during testing it was observed by EMS staff that the WTG that supply the feeder in section 34 we not turning; and did not contribute to the noise. So it is concluded that the measurements on section 34 make up a base line for the noise. By inspection for this would reduce the measured values for harmonics above 1000 hz. However, it is clear that values still exceed IEEE 776 recommended values.

Customer Tests:

Lynn

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
Lynn off Hook No Voice

Background

EMS conducted on hook and off hook test at several locations within the Lake Benton exchange. Three customers were studied in this report. The purpose of the measurement was to obtain a voltage profile vs.. frequency on the voice pair conductors and correlate the data with the data obtained on the probe wire test.

The instrument used to make the measurements is a Tektronix(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1 and 10x probe was used to measure the voltage. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintenance Service. Wilkins Consulting exported the data out of Wavestar to a standard text file. The data was formatted in text and laid out in comma separated values. The data was then imported into a Mathcad worksheet for analysis. This is that sheet.

table :=

	0	1
0	0	0
1	-0.005	-0.54
2	-0.004996	-0.54
3	-0.004992	-0.54
4	-0.004988	-0.56
5	-0.004984	-0.58
6	-0.00498	-0.56
7	-0.004976	-0.56
8	-0.004972	-0.56
9	-0.004968	-0.56
10	[illegible]	[illegible]

$time := table^{\langle 0 \rangle}$

$Volts := \left[(1 \cdot table)^{\langle 1 \rangle}\right]$

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Time domain data from the off hook measurement was exported from wavestar(tm) and imported into mathcad via the above input table.

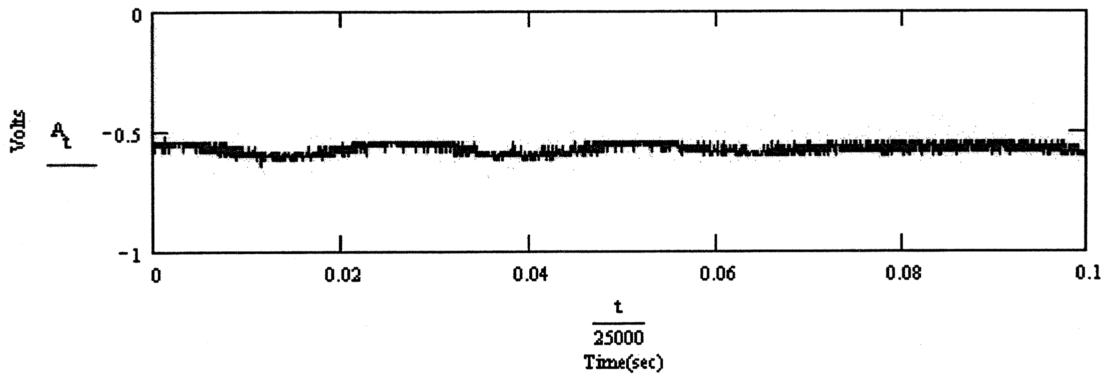
$$\frac{1}{0.005 - 0.0049960} = 2.5 \cdot 10^5$$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a Fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0 .. 2499$

$A_t := Volts_t$



Take Fourier transform:

$c := CFFT(Volts)$

$N := last(c)$

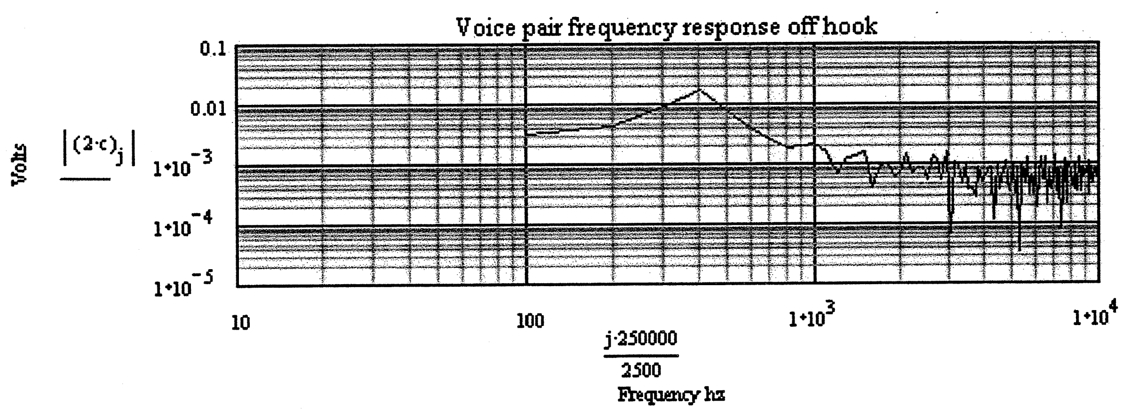
$N := 2499$

Complex frequency vector

$j := -0 .. N$

$Vres_j := c_j$

The graph given below shows the frequency response of a phone line under the influence of the feeder lines.



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Garbers

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Inductive Influence Calculation Sheet
Garbers off Hook No Voice

Background

EMS conducted on hook and off hook test at several locations within the Lake Benton exchange. Three customers were studied in this report. The purpose of the measurement was to obtain a voltage profile vs. frequency on the voice pair conductors and correlate the data with the data obtained on the probe wire test.

The instrument used to make the measurements is a Tectronix(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1 and 10x probe was used to measure the voltage. The data was stored digitally in the Oscope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintenance Service. Wilkins Consulting exported the data out of Wavestar to a standard text file. The data was formatted in text and laid out in comma separated values. The data was then imported into a Mathcad worksheet for analysis. This is that sheet.

table :=

	0	1
0	0	0
1	-0.005	0.54
2	-0.004996	0.54
3	-0.004992	0.52
4	-0.004988	0.52
5	-0.004984	0.56
6	-0.00498	0.54
7	-0.004976	0.54
8	-0.004972	0.54
9	-0.004968	0.52
10	-0.004964	0.54

$time := table^{\langle 0 \rangle}$

$Volts := \left[(1 \cdot table)^{\langle 1 \rangle} \right]$

Time domain data from the off hook measurement was exported from wavestar(tm) and imported into mathcad via the above input table.

$$\frac{1}{0.005 - 0.0049960} = 2.5 \cdot 10^{5}$$

Sampling Frequency in Hz

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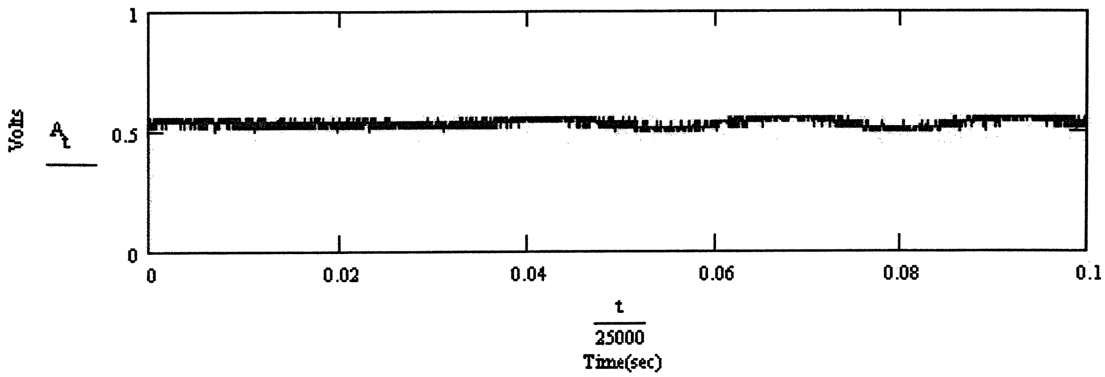
The following section converts the time domain signal (given below) to an fft(v). The FFT is a Fourier transform of a 2^m-element vector of real data measured at regularly spaced points in time.

$t := 0..2499$

$A_t := Volts_t$



Take Fourier transform:

$c := CFFT(Volts)$

$N := last(c)$

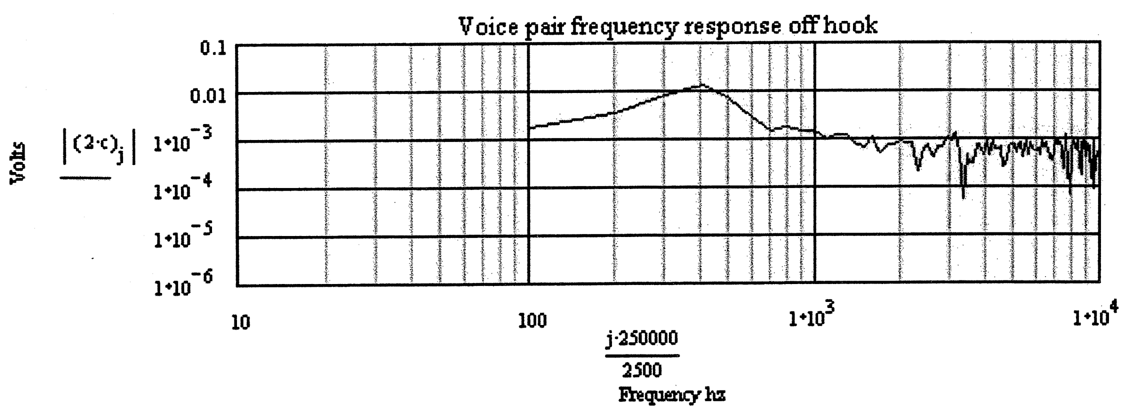
$N := 2499$

Complex frequency vector

$j := -0..N$

$Vres_j := c_j$

The graph given below shows the frequency response of a phone line under the influence of the feeder lines.



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JB

Interstate Telecommunication Cooperative
Inductive Influence Calculation Sheet
JB off Hook No Voice

Background

EMS conducted on hook and off hook test at several locations within the Lake Benton exchange. Three customers were studied in this report. The purpose of the measurement was to obtain a voltage profile vs. frequency on the voice pair conductors and correlate the data with the data obtained on the probe wire test.

The instrument used to make the measurements is a Tektronix(tm) THS720 Oscilloscope. The specifications are given in appendix A. A standard 1 and 10x probe was used to measure the voltage. The data was stored digitally in the Scope until it could be transferred to a laptop via Wavestar(tm) software. Wavestar is an interface software developed by Tektronix to interface with its instruments The data was E-mailed to Wilkins Consulting from Energy Maintenance Service. Wilkins Consulting exported the data out of Wavestar to a standard text file. The data was formatted in text and laid out in comma separated values. The data was then imported into a Mathcad worksheet for analysis. This is that sheet.

table :=

	0	1
0	0	0
1	-0.005	0.552
2	-0.004996	0.552
3	-0.004992	0.552
4	-0.004988	0.552
5	-0.004984	0.556
6	-0.00498	0.556
7	-0.004976	0.556
8	-0.004972	0.556
9	-0.004968	0.552
10	-0.004964	0.556

$\text{time} := \text{table}^{\langle 0 \rangle}$

$\text{Volts} := \left[(1 \cdot \text{table})^{\langle 1 \rangle}\right]$

Time domain data from the off hook measurement was exported from wavestar(tm) and imported into mathcad via the above input table.

$$\frac{1}{0.005 - 0.0049960} = 2.5 \cdot 10^{5}$$

Sampling Frequency in Hz

The following section converts the time domain signal (given below) to an fft(v). The FFT is a Fourier transform of a 2^{m}-element vector of real data measured at regularly spaced points in time.

$t := 0 .. 2499$

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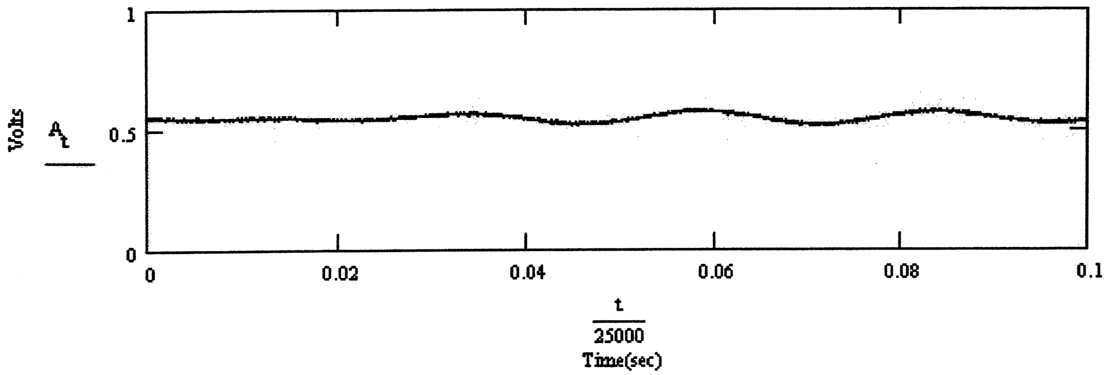
$A_t := Volts_t$



Take Fourier transform:

$c := CFFT(Volts)$

$N := last(c)$

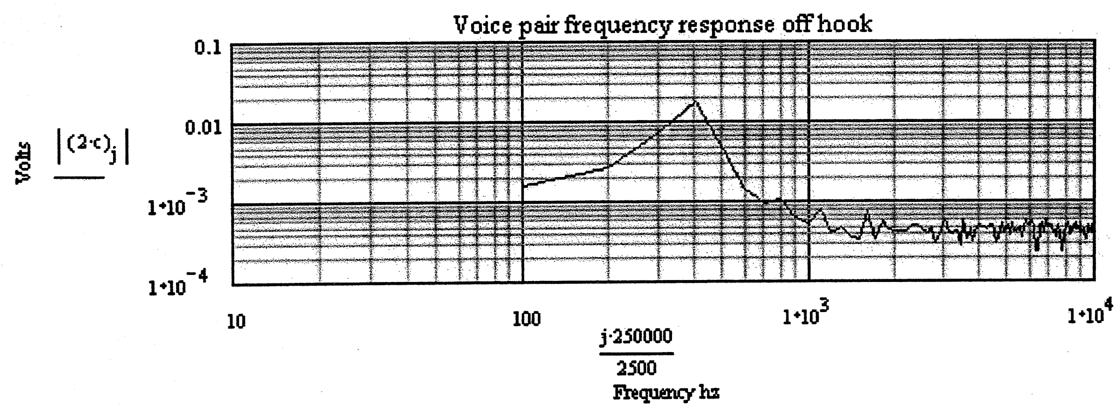
$N := 2499$

Complex frequency vector

$j := -0..N$

$Vres_j := c_j$

The graph given below shows the frequency response of a phone line under the influence of the feeder lines.



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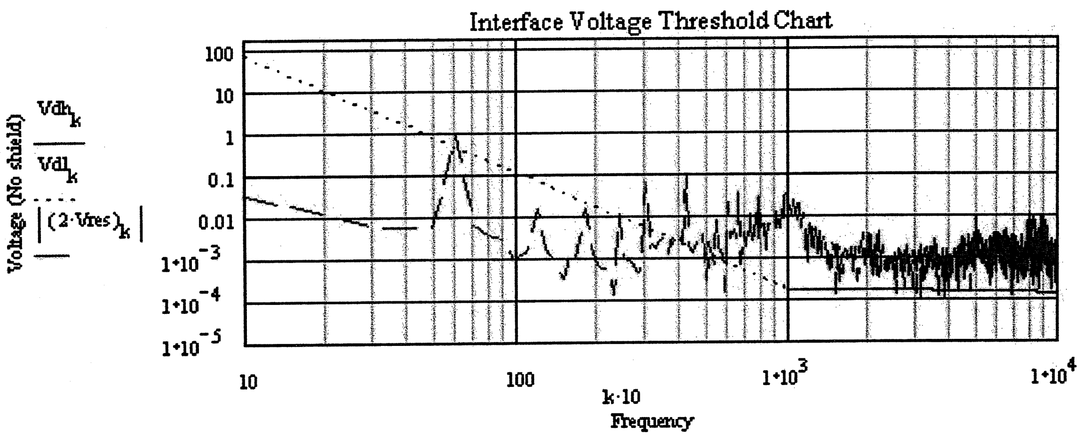
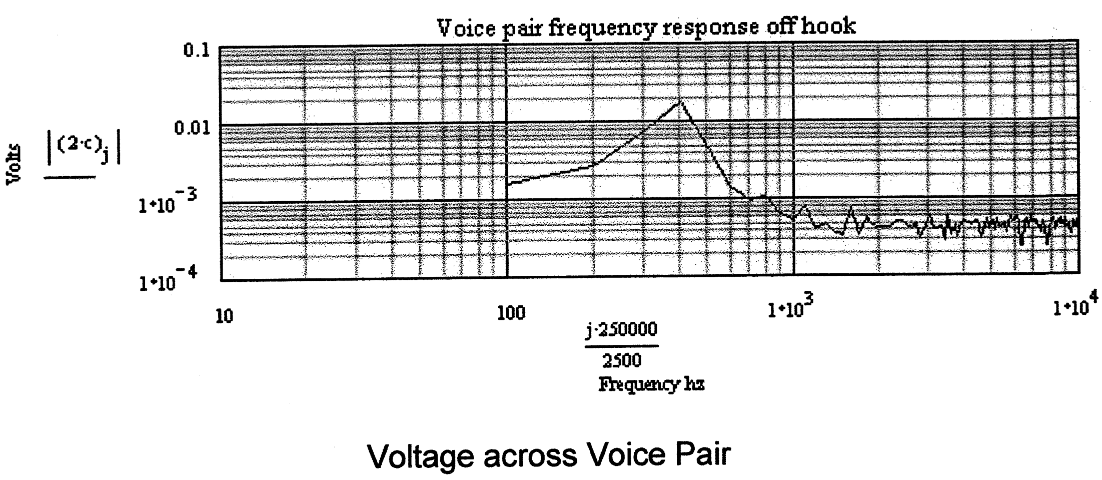
Comparative Analysis between customers and probe wire:

The data obtained from the three customers shows that the noise level is attenuated relative to the probe wire measurements. This is primarily due to the shielding on the telecommunication copper conductors. The graphs below shows the relative voltage levels vs. frequency.

Note: Graphs are only good to 50th harmonic.



Voltage across Wire Probe Section 12



Voltage across Voice Pair

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Looking at the two graphs on the previous page it can be concluded that the shielding of the telecommunication system has attenuated the noise by a factor 10. This indicates that ITC is effectively shielding it conductors. The reader is encouraged to read IEEE 367 on this subject, since the single maximum shield number referenced in the standard is a scale factor of 0.1. This means ITC has excellent shielding. Furthermore, IEEE 367 indicates that the more shielding that goes into the systems (i.e. both power and telecommunication) the amount of attenuation multiplies. For example, if a shield conductor were placed near the disturbing conductors that shield factor would be multiplied by the existing shield factor of 0.1. Lets say that that shield factor is 0.8. Then the factor would be 0.08. This indicates that owner of the collector system can configure their system to reduce the amount of noise given off by its phase conductors.

The existing design of the collector system uses an earth ground path. There are no shield conductors or ground conductors on the power lines. According to IEEEE 367 if a shield conductor is put near the disturbing conductors the induced voltage on the telecommunication cables, which run parallel, will be reduced. These values can be calculated by engineers, which work for the utility.[Ref: Carson, John R., Wave Propagation in overhead wires with ground return, Bell System Technical Journal, Vol 5, New York,1926.]

Looking at the graphs for the three customers the voltage values across the voice pairs are attenuated and most of the induced harmonics fall below IEEE 776 threshold values. However, they do not all fall below. This means that customer service is degraded. The amount of degradation depends on the amount of current flowing. So the amount of degradation is proportional to the wind speed or maximum rated current and interfering current.

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Conclusion:

ITC operates and owns a telecommunication system in the Lake Benton area, which is surrounded by the lake Benton phase 2 wind project wind turbine collector system along with others. It is know the designers of the collector system did not coordinate their design with ITC. This resulted in the collector system being put into close proximity and power lines running parallel to the copper conductors of the telecommunication system. Furthermore, it was suspected that only the Zond Wind turbines were contributing to the problem. However the data suggest all of the wind turbines makes and models contribute to this problem. So the cause is not specific to one type of wind turbine. To clarify the causes of the induced noise on ITC's telecommunication system are the following:

1. Individual Phase Current level and magnitude at each harmonic..
2. Earth resistively
3. Proximity and paralleling of the two systems (Exposure)
4. Shield Factors
5. Collector system design (including conductor spacing and transpositions).

In this case it looks like the current levels at each harmonic are primarily creating a resultant interfering current and along with exposure is inducing a voltage on the ITC copper conductors.

The magnitude of the induced voltage in the graphs is lower than what is was in the past. The reason for this is that ITC upgraded the Lake Benton exchange. ITC installed optical systems within the exchange to reduce the length of the copper runs. This reduced the amount of exposure between the two systems and reduced the amount of induced voltage on the lines. This action reduced the amount inductive interference on the telecommunication system. Also, ITC placed in inductive neutralizers on lines where the noise has interrupted service. This in effect created a shield factor that reduced the amount of noise induced on the telecommunication system.

It is suggested that the owners of the Lake Benton collector system study the amount of inductive interference is emanating from their lines. This can easily be achieved by having their responsible technical representative review IEEE standards 519, 776 and 367. With this information it they should discover that their design of the collector system does not meet what would be considered "Best Practices". Then they should coordinate with ITC and share the burden of costs for improving the telecommunication service in the Lake Benton area since it easily shown that the Lake Benton collector system exceeds the inductive standards set forth in IEEE 776.

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References:

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Carson, John R., Wave Propagation in overhead wires with Ground Return, Bell System Technical Journal, Vol. 5, New Yourk, 1926.

Kron, G., Tensorial analysis of integrated transmission systems, Part I, six basic reference frames, AIIEE trans., Vol 71, 1952

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Fink, Donald, Beaty Wayne., Standard Handbook for Electrical Engineers, McGraw-Hill Companies, 2000.

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Tektronix Inc. Wavestare™ Software.

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Appendix A

Appendix A: Specifications

Oscilloscope Specifications (Cont.)

Vertical		
✓ DC Measurement Accuracy, Average Acquisition Mode	*Measurement Type*	*Accuracy*
	Average of ≥16 waveforms	±[2% × |reading + (position × volts/div)| + (0.1 div × volts/div)]
	Delta volts between any two averages of ≥16 waveforms acquired under same setup and ambient conditions	±[2% × |reading| + (0.05 div × volts/div)]
DC Measurement Accuracy, Sample Acq. Mode, typical	±[2% × |reading + (position × volts/div)| + (0.15 div × volts/div) + 0.6 mV]	
Horizontal		
Sample Rate Range	*THS 710*	*THS 720*
	5 S/s to 250 MS/s, in a 1.25, 2.5, 5 sequence	5 S/s to 500 MS/s, in a 1.25, 2.5, 5 sequence
Record Length	2500 samples for each channel	
SEC/DIV Range (including MAG)	*THS 710*	*THS 720*
	10 ns/div to 50 s/div	5 ns/div to 50 s/div
✓ Sample Rate and Delay Time Accuracy	±200 ppm over any ≥1 ms time interval	
Delay Time Range	Zero to 50 s	

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Oscilloscope Specifications (Cont.)

Trigger		
Trigger Sensitivity, Edge Trigger Type	*Coupling*	*Sensitivity*
	DC	0.35 div from DC to 50 MHz, increasing to 1 div at 100 MHz
Trigger Sensitivity, Edge Trigger Type, typical	*Coupling*	*Sensitivity*
	NOISE REJ	3.5 times the DC-coupled limits
	HF REJ	1.5 times the DC-coupled limit from DC to 30 kHz, attenuates signals above 30 kHz
	LF REJ	1.5 times the DC-coupled limits for frequencies above 1 kHz, attenuates signals below 1 kHz
Trigger Level Range	±4 divisions from center of screen	
Trigger Level Accuracy, typical	±0.2 divisions, for signals having rise and fall times ≥20 ns	
SET LEVEL TO 50%, typical	Operates with input signals ≥50 Hz	
Width Range, Pulse Trigger Type, typical	99 ns to 1 s, with resolution of 33 ns or approximately 1% of setting (whichever is greater)	
Width Tolerance Range, Pulse Trigger Type, typical	5%, 10%, 15%, or 20%	

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Oscilloscope Specifications (Cont.)

Trigger		
✔ Trigger Sensitivity, Edge Trigger Type	*Coupling*	*Sensitivity*
	DC	0.35 div from DC to 50 MHz, increasing to 1 div at 100 MHz
Trigger Sensitivity, Edge Trigger Type, typical	*Coupling*	*Sensitivity*
	NOISE REJ	3.5 times the DC-coupled limits
	HF REJ	1.5 times the DC-coupled limit from DC to 30 kHz, attenuates signals above 30 kHz
	LF REJ	1.5 times the DC-coupled limits for frequencies above 1 kHz, attenuates signals below 1 kHz
Trigger Level Range	±4 divisions from center of screen	
Trigger Level Accuracy, typical	±0.2 divisions, for signals having rise and fall times ≥20 ns	
SET LEVEL TO 50%, typical	Operates with input signals ≥50 Hz	
Width Range, Pulse Trigger Type, typical	99 ns to 1 s, with resolution of 33 ns or approximately 1% of setting (whichever is greater)	
Width Tolerance Range, Pulse Trigger Type, typical	5%, 10%, 15%, or 20%	

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Oscilloscope Specifications (Cont.)

With P6113B Probe

Analog Bandwidth, DC Coupled	*THS 710*	*THS 720*
	60 MHz	100 MHz
Probe Attenuation	10X	
Maximum Voltage Between Probe Tip and Reference Lead	*Overvoltage Category*	*Maximum Voltage*
	CAT II Environment	300 V_{RMS}
	CAT III Environment	150 V_{RMS}
	For steady-state sinusoidal waveforms, derate at 20 dB/decade above 100 kHz to 13 V_{pk} at 3 MHz and above. Also, refer to Overvoltage Category description on page A–15.	
Maximum Voltage Between Reference Lead and Earth Ground Using P6113B Probe	30 V_{RMS}, 42.4 V_{pk}	

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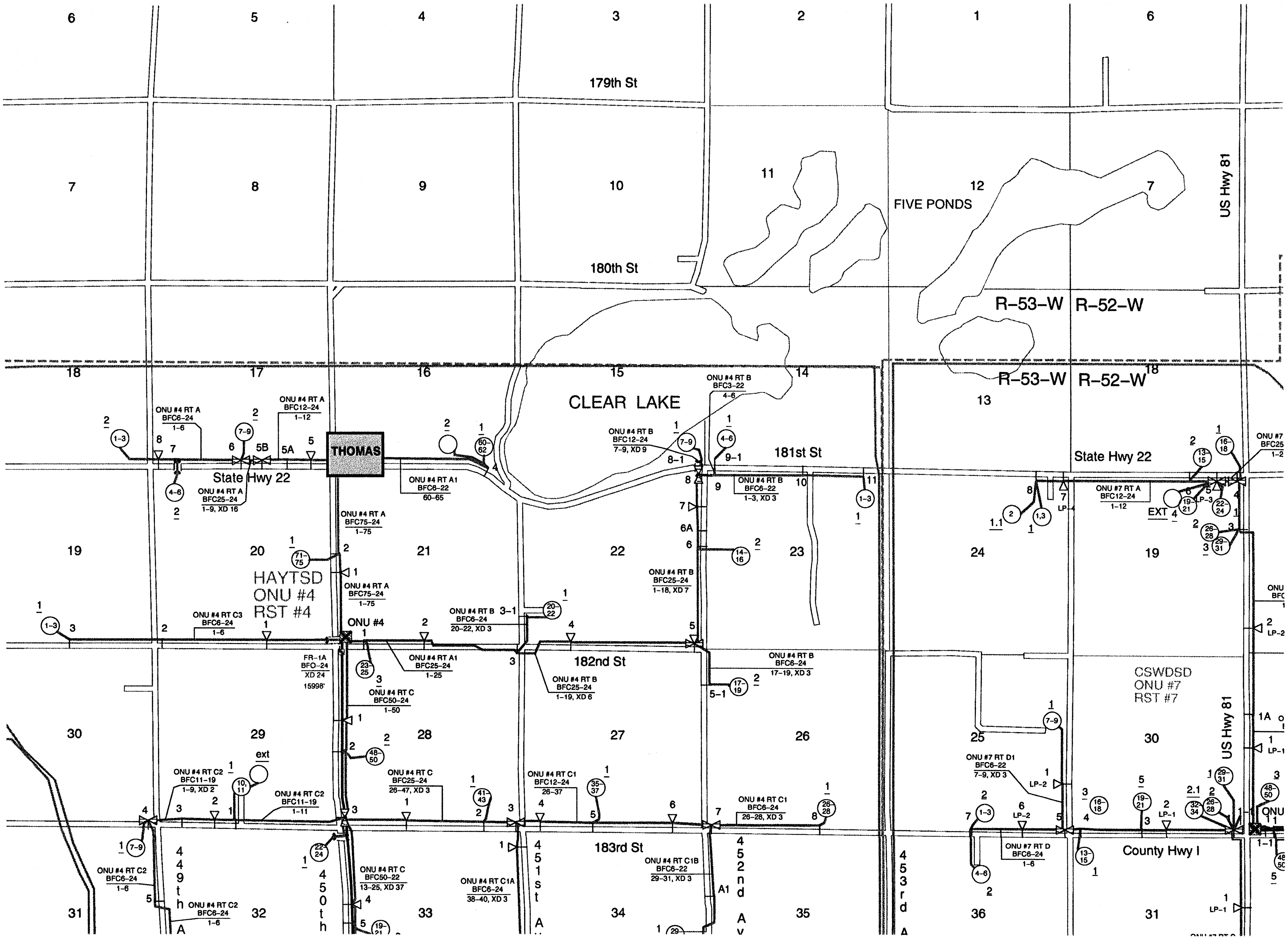
179th St
180th St
FIVE PONDS
R-53-W
R-52-W
CLEAR LAKE
THOMAS
State Hwy 22
181st St
182nd St
183rd St
US Hwy 81
County Hwy I
HAYTSD
ONU #4
RST #4
CSWDSD
ONU #7
RST #7
ONU #4
FR-1A
BFO-24
XD 24
15998'
ONU #4 RT A
BFC6-24
1-6
ONU #4 RT A
BFC12-24
1-12
ONU #4 RT A
BFC25-24
1-9, XD 16
ONU #4 RT A1
BFC6-22
60-65
ONU #4 RT A
BFC75-24
1-75
ONU #4 RT B
BFC3-22
4-6
ONU #4 RT B
BFC12-24
7-9, XD 9
ONU #4 RT B
BFC6-22
1-3, XD 3
ONU #4 RT B
BFC25-24
1-18, XD 7
ONU #4 RT B
BFC6-24
20-22, XD 3
ONU #4 RT A1
BFC25-24
1-25
ONU #4 RT B
BFC25-24
1-19, XD 6
ONU #4 RT B
BFC6-24
17-19, XD 3
ONU #4 RT C3
BFC6-24
1-6
ONU #4 RT C
BFC50-24
1-50
ONU #4 RT C
BFC25-24
26-47, XD 3
ONU #4 RT C1
BFC12-24
26-37
ONU #4 RT C1
BFC6-24
26-28, XD 3
ONU #4 RT C2
BFC11-19
1-9, XD 2
ONU #4 RT C2
BFC11-19
1-11
ONU #4 RT C2
BFC6-24
1-6
ONU #4 RT C
BFC50-22
13-25, XD 37
ONU #4 RT C1A
BFC6-24
38-40, XD 3
ONU #4 RT C1B
BFC6-22
29-31, XD 3
ONU #7 RT A
BFC12-24
1-12
ONU #7 RT D1
BFC6-22
7-9, XD 3
ONU #7 RT D
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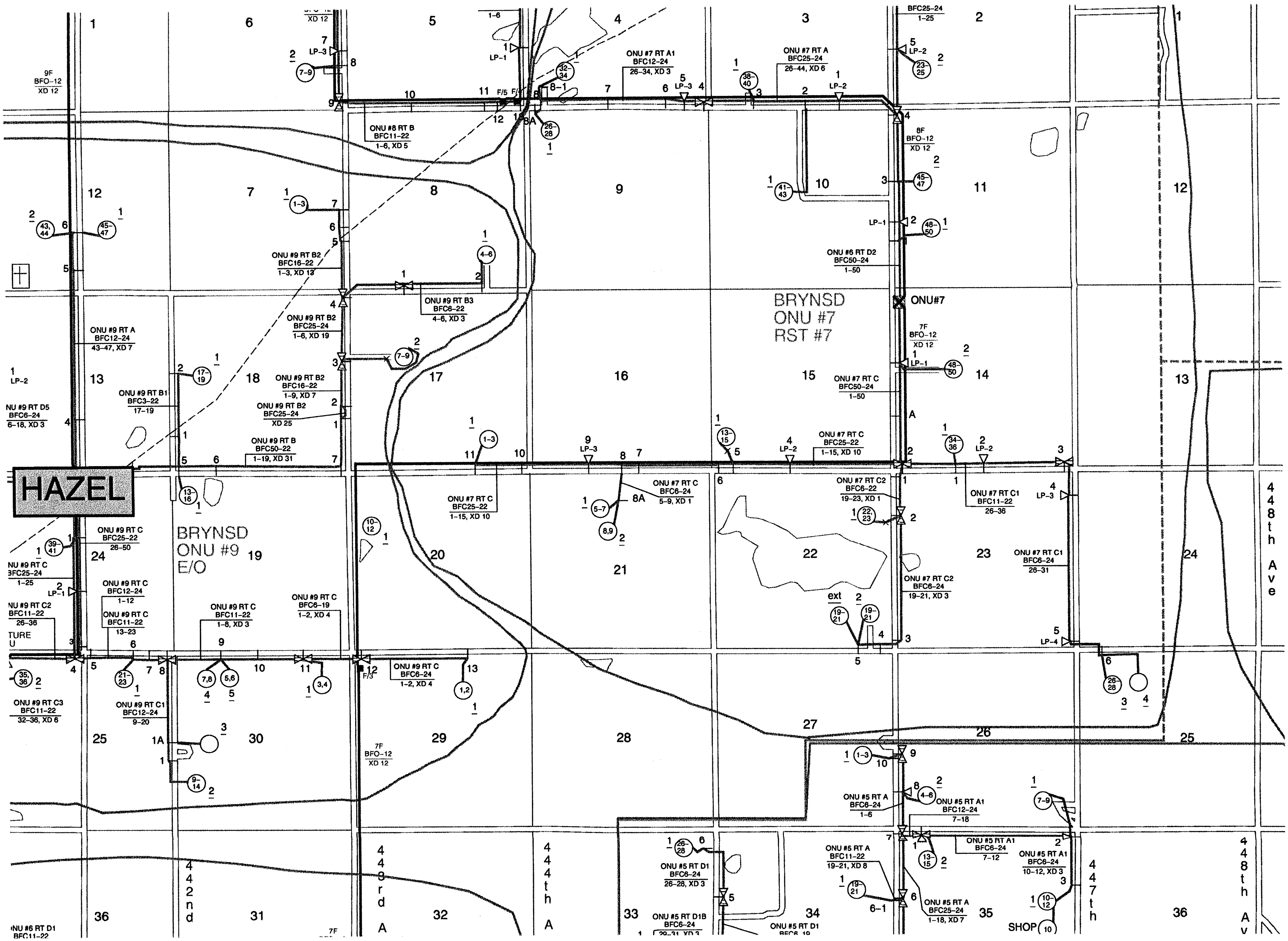
452nd Ave
453rd Ave


HAZEL
BRYNSD
ONU #9
E/O
BRYNSD
ONU #7
RST #7
ONU#7
ONU #8 RT B
BFC11-22
1-6, XD 5
ONU #7 RT A1
BFC12-24
26-34, XD 3
ONU #7 RT A
BFC25-24
26-44, XD 6
ONU #6 RT D2
BFC50-24
1-50
ONU #7 RT C
BFC50-24
1-50
ONU #7 RT C
BFC25-22
1-15, XD 10
ONU #7 RT C
BFC6-24
5-9, XD 1
ONU #7 RT C2
BFC6-22
19-23, XD 1
ONU #7 RT C1
BFC11-22
26-36
ONU #7 RT C1
BFC6-24
26-31
ONU #7 RT C2
BFC6-24
19-21, XD 3
ONU #9 RT A
BFC12-24
43-47, XD 7
ONU #9 RT B1
BFC3-22
17-19
ONU #9 RT B2
BFC16-22
1-3, XD 13
ONU #9 RT B3
BFC6-22
4-6, XD 3
ONU #9 RT B2
BFC25-24
1-6, XD 19
ONU #9 RT B2
BFC16-22
1-9, XD 7
ONU #9 RT B2
BFC25-24
XD 25
ONU #9 RT B
BFC50-22
1-19, XD 31
ONU #9 RT C
BFC25-22
26-50
ONU #9 RT C
BFC12-24
1-12
ONU #9 RT C
BFC11-22
13-23
ONU #9 RT C
BFC11-22
1-8, XD 3
ONU #9 RT C
BFC6-19
1-2, XD 4
ONU #9 RT C
BFC6-24
1-2, XD 4
ONU #9 RT C1
BFC12-24
9-20
ONU #9 RT C3
BFC11-22
32-36, XD 6
ONU #5 RT A
BFC6-24
1-6
ONU #5 RT A1
BFC12-24
7-18
ONU #5 RT A1
BFC6-24
7-12
ONU #5 RT A1
BFC6-24
10-12, XD 3
ONU #5 RT A
BFC11-22
19-21, XD 8
ONU #5 RT A
BFC25-24
1-18, XD 7
ONU #5 RT D1
BFC6-24
26-28, XD 3
ONU #5 RT D1B
BFC6-24
9F
BFO-12
XD 12
8F
BFO-12
XD 12
7F
BFO-12
XD 12
BFC25-24
1-25
SHOP
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444th A
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312 4th Street West
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Clear Lake, South Dakota 57226-0920

Phone 605-874-2181
Fax 605-874-2014
Web http://www.itc-web.com

September 14, 2000

Mr. Kalyan K. Mustaphi
Executive Engineer
Northern States Power Company
1518 Chestnut Ave. North, Annex
Minneapolis, MN 55403

Dear Mr. Mustaphi:

As you know, we have been working with our engineers, your staff, and your contractors, to resolve the problem of the noise induced onto our telephone system as a result of your installation and operation of the wind generation systems in the Lake Benton, MN area. At this point, I thought it appropriate to advise you of the latest status of that situation.

Over the last nine months, we have done some very extensive test and measurement work on our telephone cable system. The results of that work confirmed that the noise induction is directly related to the power generated by the wind farm. To put it very simply, when the wind is not blowing there is no noise problem. As soon as the wind comes up, and the windmills start turning, the noise problem appears. *

Our engineers tell us that the harmonic signatures of the wind system are very distinctive; that is, unlike anything seen with the typical central station oriented power system. They believe that this is a result of the "power electronics" being used in the wind generation system, and the fact that those power electronics are dispersed throughout the Lake Benton exchange area. The problem is further complicated by the close paralleling of NSP's sub-transmission facilities and our existing telephone cables.

Despite the unique nature of the induced harmonics, we have been able to use some specialized equipment to combat the problem. By installing Induction Neutralizing Transformers (INT's) at carefully selected locations on our existing cable system, we have been able to partially mitigate the noise problem. Some noise is still present, but it has been reduced to levels that can be tolerated by our customers on a temporary basis.

The concept of the "temporary basis" is significant because we are in the process of a major upgrade to the Lake Benton exchange. The upgrade design will place a significant amount of fiber optic cable in the exchange as the backbone system, along with appropriate electronics to utilize the fiber, and new copper facilities from that electronic equipment to individual customer locations. The purpose of the upgrade was to increase the available bandwidth to our customers, in accordance with the State Telecommunications Modernization Plan (STMP), so that enhanced services may be offered. This upgrade is in process at this time. The new cables have been installed, the new electronics are being procured, and we anticipate cutting customers over to the new system within the next few months.

To date, we have expended significant time and material resources on this problem. There have been significant costs involved and, under the circumstances, we do not feel that ITC should have to bear the burden of these costs alone. We fully expect that NSP and/or NSP's vendors, as appropriate, will participate.

Beyond that, however, are the unknown costs that may be incurred with the new telecommunications system being placed in service in the Lake Benton exchange. While we anticipate that the new system will be less susceptible to power induced noise than the old system (due to the use of fiber-optics), this assumption may not prove to be correct. We have no way to know or assess the effects of power induced noise on the field electronics of the new system until it is deployed. However, there is certainly some possibility that we may have to take additional steps to mitigate an induction problem on the new system. If that proves to be the case, we would also expect NSP to participate in covering those costs. We will know more in the next few months as we cut over to the new system, and we will keep you advised.

As I mentioned earlier, this discussion is intended to keep you informed as to the latest status of the situation. Please advise me of any comments you may have.

Sincerely,

Dean Anderson

Dean Anderson, Manager

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August 22, 2001

Mr. Kalyan K. Mustaphi
Executive Engineer
Exel Energy
1518 Chestnut Ave. North, Annex
Minneapolis, MN 55403

Dear Mr. Mustaphi:

In a letter dated September 14, 2000 I provided you an update on the progress we had made to resolve the problems caused by the noise induced onto our then existing telephone system in Lake Benton, Minnesota as a result of the installation and operation of the wind generation systems in the Lake Benton area.

That letter informed you that we had been able, through an extensive testing process and the procurement of some specialized equipment, to bring the induced noise levels on our facilities down to a point that our customers could tolerate the noise and use their telephones. We also noted that we were in the process of rebuilding our telephone exchange and that the effect of the noise induction on that new facility was unknown.

At this point we have installed the new system in the Lake Benton exchange and have operated it for several months. We now know that, as we expected, the addition of fiber optics, the re-routing of some of the new copper exchange cables to increase separation from your 35kV sub-transmission (feeder) facilities, the fact that the copper exchange cable is new, and the shortened lengths of the new copper cable facilities have all combined to reduce the induced noise problem significantly.

Please note that the induced noise has only been reduced; not eliminated entirely. It appears that we will need to utilize some of the special Induction Neutralizing Transformers purchased for the old system at selected locations on the new system in order to get the induced noise levels down under the 20 dBrnC level (which is an industry standard for good telephone service). The primary locations where we still have some significant noise levels are for some of our customers located near your substation, and its associated capacitor banks, southeast of the town of Lake Benton.

As I noted in my September 14, 2000 letter, we fully expect that the entities involved in the creation of the noise problem will be the entities which will pay for the corrective actions it took to resolve the problem. While we are aware that Exel Energy has contracted with others for the wind generation systems, we have no way of knowing who all those vendors are (or were), and we believe that Exel Energy is ultimately the responsible party in any event.

To date, we have invested in excess of seventy-nine thousand dollars ($79,533.97) in the process of testing for the induced noise, planning the remediation measures, purchasing and installing the Induction Neutralizing Transformers (INT's), and some follow-up testing to ascertain and confirm the degree of noise reduction, all on the old existing system. In addition, that amount includes the costs of some selective testing on the new system to determine the degree of noise induced on it. Note that the total does not include any costs associated with design modifications which were made to the new system, prior to construction, to help mitigate induced noise.

At this point we feel confident of our new system and of our abilities to mitigate the degree of noise presently induced on it to feel that we are now in a position to accept a settlement with Exel Energy based on the costs incurred to date (see above). We anticipate that such a settlement would likely be a final settlement of the issue, barring any changes in the wind power system and associated sub-transmission system in the Lake Benton area. Since we have no control or input into power system changes, we will reserve the right to revisit this situation with Exel Energy in the future if circumstances change.

It should also be noted that the induced noise problem in the Lake Benton area was very much an avoidable problem. Had Exel Energy done any coordination with our company when the sub-transmission system was being planned, there could have been some minor line routing changes made which would have significantly reduced the magnitude of the problem in the first place. We would hope that, as more dispersed generation projects are implemented by Exel Energy in the future, such coordination would occur before the projects are all planned and built. *

In the event that you should have any questions on this matter, please contact me. If not, please advise me when we may expect to receive settlement.

Sincerely,

Dean E. Anderson
General Manager

May 3, 2002

Jerry Heiberger
General Manager
Interstate Telecom
312 4th Street, West
PO Box 920
Clear Lake, SD 57226

Ref: SD538 – 1.0

Dear Jerry:

We have received and reviewed a copy of the Xcel Energy letter, authored by a Mr. Altman, and dated February 15, 2002. The letter was addressed to a Mr. Hartman of the EQB Staff. This letter apparently addresses an EQB letter of December 21, 2001, related to the telephone noise problems experienced in the Lake Benton, MN area.

The letter does not accurately represent the noise problems that were experienced in the Lake Benton area. In order to attempt to shed light on the problem, we would like to address some of the statements made in Mr. Altman's letter:

1. First, and most disturbing is the comment made on page 2 of Mr. Altman's letter, wherein he states that there is "the absence of any compelling evidence that suggests any improper operation of the wind farm is creating the noise…..". This statement is simply false. Perhaps the most compelling evidence that the wind generators are causing a problem is the fact that when the wind does not blow, and the generators are shut down, the telephone system operated with near perfection. As soon as the wind came up and the generators began operating, the noise appeared. Note that the noise referred to was so great that nearly all of the Lake Benton exchange customers had some problems using their telephones, and many experienced noise so severe that they could not actually use their telephones. We actually experienced this "no wind" to "wind" condition twice during our testing processes at the exchange.

2. Mr. Altman claims that "immediately" after being notified of a possible noise problem, Xcel (NSP) placed some sort of instrumentation ("recorders") at their Buffalo Ridge substation, and at interconnection sites "Alpha", "Golf", and on each of the "six feeders at the Buffalo Ridge Substation". There is no indication of what type of instrumentation was used, nor how it was connected into the electric system's circuitry.

   Given the typical electrical lineman's perspective, however, it is quite likely that whatever instrumentation was used was connected at or on the substation or interconnection sites' buswork. The problem with that arrangement is that the measuring equipment is then behind (electrically) the existing capacitor banks, which act as traps for harmonic frequencies, thus preventing accurate measurements of what is really going on within the electrical system. Note: this is very similar to the practice (called trapping), which is common to many Cable Television systems, and which prevents customers from watching channels they have not paid for. In this case, it would prevent the instrumentation from seeing the higher frequency harmonics.

3. On page 2 of Mr. Altman's letter (and in some other paragraphs), there is reference made to IEEE guideline 519 – 1992. Unfortunately, this guideline is quite old (1992 vintage). It was written in a time when the concept of distributed generation was not on anyone's agenda. That doesn't make it a bad

In this case, it is not hard to figure out what that coupling mechanism is. Basically, Xcel constructed their sub-transmission system right over the top of the backbone distribution cable of the existing telephone system, mile after mile, with no coordinating activities at all. The combination of close proximity and many long miles of parallel facilities resulted in a major problem for the existing telephone system.

The need for advance planning and coordination was stressed on more than one occasion, at meetings held at the wind generation facilities near Lake Benton. Despite these discussions, ITC had to learn of the wind farm expansion plans north of Lake Benton (in the Hendricks, MN area) from articles in the local newspapers. XCEL energy, and/or their contractors, have never made any effort to coordinate their activities with the local telephone utility.

Had XCEL or their contractors used any precautions and/or coordination measures during the wind farm planning process, the impact to the telephone network could have certainly been minimized, and possibly would have been totally eliminated. Throughout the testing and trouble-shooting process, the telephone company and Martin Group encouraged NSP (XCEL) to participate, and also provided them with the test results obtained. This courtesy was never returned. Further, when NSP did send a technician to join the testing process, they did so with such antiquated and unreliable test equipment that there was no possible way for them to draw any conclusions from their involvement.

It is and was clear, as a result of testing and direct observation, that the noise problems at Lake Benton were caused by the wind generators and the close proximity of the electrical sub-transmission system to existing telephone cable facilities. The problem was so severe that drastic corrective steps had to be taken rapidly in order to avoid the possibility of a failed E911 call or other communications failure. The telephone company took the necessary steps because it was forced to for the good of the customer/owners. However, we continue to believe that the parties responsible for the problem should bear the cost of the necessary corrective actions.

If you have any questions or comments, please feel free to call me at 605-995-5492.

Sincerely,
Martin Group, Inc.

Keith A. Bartels, P.E.

KAB/jct

Problems Begin

- After completion of phases I - III, approx. 200 turbines were located within Lake Benton Exchange.
- Summer 1999 - ITC customers in Lake Benton exchange began to complain about interference/noise.
- 100% of 850 Lake Benton access lines were affected.

January 25, 2005

Ren Preheim
Networks Operations Manager
Interstate Telecommunications Cooperative
PO Box 920
312 4th Street West
Clear Lake, South Dakota 57226

Dear Ren,

As we discussed last week, Xcel Energy is committed to finding a solution to the telecommunications interference problem your company and customers have been experiencing in and around the area near Lake Benton, Minnesota. I have been assigned to spearhead the effort for Xcel Energy.

I am working to expedite the process for bringing a consultant on this project. The skills needed are available from consultants we already have working with us. They already have familiarity with the issues, and therefore would be more likely to be in a position to quickly identify the exact sources of the problems as well the best methods to mitigate the effects of those problem sources.

In addition to working on the existing issues near Lake Benton, Xcel's goal is to have the consultant also evaluate any impact the proposed 115kv line to White Substation might have on your facilities. We would be evaluating the impacts of this 115kv line in conjunction with the IEEE Standard 776 as well as IEEE 519.

Our goal is to work with your company to identify and resolve existing issues as well as potential issues involving the proposed 115kv line to White Sub. You can look forward to our continued cooperation in finding the answers needed for both of our facilities to productively co-exist.

I will keep you informed to our progress in dispatching consultants to this project.

Sincerely,

Gary Karn
Project Manager -Transmission Asset Management
Xcel Energy - 414 Nicollet Mall – 6th Floor
612-330-6377